Models, Rules and Behaviours: Investigating Young Children's Modelling Abilities Using an Educational Computer Program

by

Eleni Maragoudaki

A Thesis submitted in fulfilment of
the requirements for the degree of
Doctor of Philosophy

in

University of London, Institute of Education

2007

Hereby I declare that the work presented in this thesis is my own.

ABSTRACT

A model can be built to represent aspects of the world establishing at the same time a world on its own. It might be considered in terms of its relation to the world or as an artefact having an identity related to the nature and kind of the modelling tool used to make it. The present research focuses on models being built by a computer-based modelling tool called WorldMaker (WM), which allows models to be built in terms of objects and the actions they perform. It is intended to be accessible to younger pupils. Therefore, children from the last years of primary and the first years of secondary education (aged 10-14) participated in the research.

The research was carried out in three stages. The preliminary study aimed to explore children's ability to use WM, as well as possibilities for the kinds of tasks that might be used with it. The first main study focused on rules, which define actions in WM, and their meaning for children. It mainly investigated children's understanding, use and thinking about models in the form of WM rules. The second main study looked into children's ability to think of situations in terms of structures as well as their understanding about the relation between models and reality. Its primary concern was to find out if children think about situations presented as stories or computer models in the 'modelling' way required by WM, that is, in terms of objects and the actions they perform. In the research tasks the children were called on to approach the modelling process by creating or exploring a model, as well as by describing and explaining the formal behaviour of a model or interpreting the meaning of it.

It was found that the children were able to use WM as a modelling tool; they could represent actions in the form of a WM rule and they were able to think of situations in terms of objects and actions. Besides, the relation between models and reality is an issue when young children are involved with the modelling process.

To my parents
and the memory
of my uncle Giorgos

ACKNOWLEDGEMENTS

My most sincere thanks go to:

- My supervisor, Jon Ogborn, who has been a continuous source of inspiration during these years; he was the one who made this work possible.
- Richard Boohan for spending a great deal of time introducing me to the modelling ‘world’. His support was constant and his guidance and help crucial throughout the thesis.
- Joan Bliss and Harvey Mellar for their vital advice.
- All the pupils and teachers for participating in the research.
- My friends Manolis Kanakis, Xanthi Karadima and Fani Stylianidou for being my ‘home’ in London.
- My parents and sisters for the unparallel support and encouragement through all these years.
- My husband, Dimitris Sarris, who was my fellow traveller in this long, solitary and sometimes tempestuous trip.
- The ‘Alexander S. Onassis’ Public Benefit Foundation for proving financial support for the accomplishment of this thesis.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

1.1 What I was looking for when planning my research

This thesis is the outcome of a process that was ‘sparked off’ during my postgraduate studies in science education. In my MA dissertation I was looking for the researchers’ thinking when they carry out studies into children’s ideas about the particulate nature of matter. One of the conclusions I came to was about the need to:

> “… *use assessing instruments for children’s ‘conceptions’ which will provide the chance for a child to build his/her own particular model according to the rule that he/she regards as necessary, and which are probably not identical to scientific rules.*”
>
> (Maragoudaki, 1991, p. 70)

Then, a new computer-based modelling tool, named WorldMaker (WM), was created at the Institute of Education, University of London, an outcome of a National Council for Educational Technology (NCET) program funded by the Department of Education and Science (DES). At that time, only simulation programs were available for young children. The modelling programs available involved difficult ideas, such as defining the mathematical relations between variables, an impossible task for these children. WM was designed to enable even children of primary education to create their own models. Children are asked to see the world in terms of objects and what they do – a way of thinking that is natural for them. To create a model, they simply have to specify the rules that govern the behaviour of the objects, which are then placed on a grid of cells to interact.

WM looked to me like a new and promising tool that could give young children a chance to formulate and express their conceptions/ideas about the particulate nature of matter. Children could build a computer model by defining their own WM rules. Later they could test the model and refine it, aiming for closer alignment with the way they see the specific body of scientific knowledge.

That is how my ‘encounter’ with WM started when I decided to focus on it in order to develop a PhD thesis. The different stages of my research reflect a step-by-step process of approaching WM. In the preliminary study, having no clear idea about how children could manage with WM, my main concern was to find out if children in the last years of primary education – according to the National Curriculum for technology (DES/Welsh Office, 1990) children of this age should start dealing with modelling – are able to use WM and to identify possibilities for the kinds of tasks that can be used with it. In the first main study, having seen that WM could be a meaningful tool for children and bearing in mind that the definition of a rule is a key process in modelling with WM, as well as the fact that the relation between reality and situation to be modelled is an issue for children, the focus was on exploring the way children understand and use rules. In the second main study, children from the first years of secondary education were involved due to the insufficient numbers of computers in primary schools and the focus was again on rules. But this time rules were considered from a different and rather more general perspective. Having already investigated the way children read, draw, create, evaluate and consider different WM rules in the first main study, I tried to find out if the way children think of situations can have an appropriate relationship with the way situations are defined in WM – in terms of actions and conditions of actions. For this reason the children were mainly asked to compare different elements of a computer model such as the situation to be modelled, the model itself and reality. Furthermore, two issues explored in the first main study were explored again; children's ability to draw rules and the way they see the relation between models and reality. As a final task that would epitomize how far children can go with WM, the children were called on to create their own WM model to represent a situation.

Although this research began as an evaluation of WM and I was hoping to verify my first thought when I saw WM "*This is really the tool I was looking for*", it ended up differently. The tasks in the preliminary and the first main study were very much 'attached' to the use of WM as a modelling tool. The children did not always have to 'put their hands on' WM, but they were called on to reflect on elements of it. In the second main study, there was a minimum involvement of WM. The majority of the tasks were not related to children's performance in using WM; they could have been administered even if the children had been introduced to the modelling process using a different tool. The purpose was to find out if the way that WM asks children to think about actions and conditions of actions is a natural thing for them to do, and whether this kind of reasoning can provide to children a unified way to go beyond what are like to the way things work, helping them to move from a concrete to a more abstract level of thinking.

During the research, I was concerned to give the children freedom to spell out their thinking and understanding through model construction. Although some of my results could be helpful for a teacher who wants to use WM in his/her lessons, in my research WM was not used in a classroom setting for testing its effectiveness as a teaching and learning tool. This research was more of an evaluation of the tool in terms of being able to explore aspects of children's thinking when modelling rather than of its effectiveness as a modelling tool – to teach children about models and modelling. Questions such as "*What do children learn about models and modelling when using it?*" or "*How much science do children learn when using it?*" were not under consideration. For this reason, the tasks mainly explored children's reasoning about every day life situations and not their scientific knowledge. Thus, although I was attracted to WM by thinking of it as being a powerful expressive tool for children's scientific knowledge, in the end I used it in a more informal setting.

1.2 Outline of the thesis

In Chapter 2, main issues related to models, modellers and the modelling process in education are explored. The tool used in the research, WM, is presented alongside other computer-based modelling tools.

Chapter 3 is about the general research questions that apply to the research as a whole and those specific to each stage of the research.

The design and the outcomes of the preliminary study are presented in Chapter 4.

Chapter 5 is about the rationale and the design of the first main study. After presenting the specific research questions, the criteria used for constructing the research tasks and the tasks themselves are provided. The chapter closes with the organisation of the study.

The analysis of the results of the first main study is described in Chapter 6. It consists of two parts, one is about children's performance when learning basic ideas about

WM before using WM and the other concerns their understanding of rules when they have their ‘hands on’ WM. This is followed by a summary of the results.

In Chapter 7 (which has a similar structure to Chapter 5), the rationale and the design of the second main study are presented. The presentation of the research questions that apply to this study, the criteria for the tasks and the tasks together with the organisation of the research are given.

Chapter 8 presents the results of the second main study. The first part of the analysis is about the tasks investigating children’s tendency to look for structures. Next, children’s performance in drawing rules and writing stories is discussed. In the last part, replies to a questionnaire about how to improve and construct a WM model are analysed. Finally, some concluding remarks are made.

Chapter 9 summarises the research findings. Firstly, all the specific questions for each stage of the research are answered. Secondly, the general research questions as well as the children’s performance across the different modelling activities are discussed. Where possible, the research findings are placed in the context of other research work. Finally, the results are further synthesised, in the form of advice given to a teacher who might wish to implement WM in the classroom. The thesis closes with a discussion placing the research findings in a wider context.

CHAPTER 2

Computer Modelling for Young Children

2.1 Introduction

From early childhood, children enjoy listening to fairy-tales such as the one about the frog that was transformed into a prince when a girl kissed him after appreciating his good character. Later, in their school years, although children know that Batman is not flying over the streets of New York, they still enjoy reading the adventures of the immature magician Harry Potter, watch cartoons on TV and many of them play computer games where the heroes exercise their magical power in the long-standing war of right against wrong. Teachers in schools tell the story of Midas, who changed his own daughter into a gold statue, using the Gods' gift of changing what ever he touches into gold, as an example of how harmful greediness can be. At the same time, adults offer children objects such as dolls, matchbox-cars and later board games like monopoly or chess and children play the role of a parent, a driver, an estate agent or a soldier. By playing such roles children are preparing for the behavioural patterns required of adults (Marx, 1984). During role-play, although children draw on experiences of everyday life, they can enjoy the freedom to decide about the boundaries of the world in which they are going to perform – quite often they turn the rules 'upside down'.

All these examples show that there is a fantasy 'world' that children are called on to approach very early in life, either by observing it as it evolves or by performing a role in it. The prince, Harry Potter, the cartoons, the computer game heroes, children playing the role of parents and Midas, all stand as representatives of different characters, each one having specific, personal as well as social characteristics, whether desirable or not.

In this research, the idea of something standing for something else, that is, representing it, is very widely used and explored in an educational setting. The representational tool used is a computer program, specifically, a program called

WorldMaker (WM). This chapter is about the main issues related to educational uses of modelling and computer-based modelling tools accessible to young children.

Firstly, the emphasis is on three elements involved in the representation process, models, modelling and modellers. Then, in section 2.3, WM is presented alongside other modelling tools. Because WM is the main focus of the research, it is discussed at greater length and the characteristics of other tools are compared with it. Afterwards, the issue of computer modelling and natural reasoning is explored with an emphasis on WM. Finally, I will try to summarise the main issues arising from research, related to models, modellers, modelling and computer-based modelling tools, so as to put my own research questions (see Chapter 3) in this wider context.

2.2 Thinking about models, modelling and modellers

Two concepts very much related to the representation process are *model* and *modelling.* Firstly, these terms are defined and special attention is paid to the *modellers* who carry out the modelling process and who are the creators of the models. Then, the focus is on computational modelling in education and the way it is applied in the National Curriculum.

2.2.1 3M (Models – Modelling – Modellers)

The term *model* can be used in nearly every aspect of human life, from the science laboratory to the meeting rooms of a building society. One could cite the atomic model, the hydrodynamic model of an electric circuit or the engineering model of a new aircraft. In all these cases, what is involved is "... *using one thing (a model) in order to think about another, and choosing for the model something more or less idealized or simplified*" (Ogborn, 1994, p. 11). A model then might be an object, a drawing, a diagram, a mathematical formula, or any other possible means of representing either abstract entities such as the idea of freedom or gravity, or specific objects/systems such as the central heating of a building or the solar system (Raghavan, Sartoris and Zimmerman, 2002).

Using the terms *source* and *target*, taken from Black (1962), the situation to be modelled can be thought of as the source and the model to represent it as the target. The idea here is that the relation between model and situation to be modelled is in some respects like a metaphor. There are aspects of the source of the model which are transferred to the target. Generally speaking, *modelling* is the process that produces a representation (a model) which takes the place of the source (whatever its nature), in order to describe it and make it more understandable (Giordan, 1991). During the modelling process, an *analogy* is drawn between the source and the target. And according to Duit (1991, p. 651) "*it is the analogy relation that makes a model a model*". The analogical relation between the source and the target can be allied either to attributes (such as appearance, shape or colour) or to structures (Duit and Glynn, 1996). In the Gentner's structure mapping theory, the soundness of an analogy is strongly influenced by commonalities attributed to structural relations and not at all to surface similarities (Gentner, Rattermann and Forbus, 1993). The structures defining the analogies between a source and different targets may vary. For instance, in creating a model of an epidemic, certain aspects of the phenomenon might be included in certain types of models. A computer model can describe how the epidemic is transmitted or a mathematical equation can calculate the size of population expected to become ill in a certain amount of time. During the modelling process, the analogical relations shared by the source and the model need to be specified for the model to be able to serve its purpose. A key issue in that course of action is the modellers' view regarding the relation between a model and reality. According to the modellers, can a model stand on its own or can it be anything other than a replica of reality?

In general, there is a number of ways in which models might be categorised. Three of them, useful for the design of my research tasks are as follows:

- Regarding the nature of the source, models may be classified as *realistic* (in the sense that they try to explore the real world), *unrealistic* or *abstract.* A model where foxes are eating rabbits is feasible; a model presenting rabbits eating foxes can be equally well be made but is not realistic. If objects with no identity (perhaps called A and B) are involved in the actions, then the model is abstract (no source, or an abstract source).
- A model may represent either an event where a change over time takes place, like flow of water in a tank, or represent an unchanging state of affairs, typically some structural relations such as a family tree. In the first case a *dynamic* model is constructed, while in the second a *static* one (Miller *et al.*, 1993).

- The entities involved in models may be *objects* or *variables.* One instance of a model about objects is one dealing with a scheduling problem, like the building of a house, considering the need to lay foundations, build walls, put on the roof, provide gas, etc., all in the best order (Ogborn, 1990). By comparison, a (dynamic) weather forecasting model will be built using variables, such as temperature, pressure, wind velocity, etc., all varying in time and from place to place. When specifying any model including variables, one must be able to identify the relevant variables and to specify the functional relations between them.

Moreover, the different kinds of reasoning involved in the modelling process can be characterised as qualitative, quantitative and semi-quantitative (Bliss *et al.*, 1992):

- *Quantitative* reasoning can involve a variety of aspects, from recognising simple numerical relations, through working with sets of numbers and comparing sizes and magnitudes, to manipulating algebraic relations.
- *Qualitative* reasoning lies at the opposite extreme of quantitative reasoning. It is purely about "*... making categorical distinctions and decisions*" (Bliss *et al.*, 1992, p. 2). Deciding which is the best period or the best place to go for holidays and planning ahead what has to be done to make that possible (i.e. to take leave, to book tickets and accommodation, to buy the suitable clothing) are cases in which qualitative reasoning is involved.
- *Semi-quantitative* reasoning is applied in the case of considering a complex system in which the relations between the different parts of the system cannot be quantified by involving quantitative reasoning. What can be specified is only the direction of the effects that one part of the system has on the other. An example is saying that a sufficient diet and enough exercise both have a positive effect on health.

This differentiation applies not only to the kind of reasoning involved in the modelling process but also to models themselves.

In science, the term model – among other meanings – is related to a specific body of scientific knowledge explaining a specific aspect of reality. A concern in science education is how to develop a pupil's body of knowledge towards the scientific one. According to Gilbert and Boulter (1998), this process can be facilitated if children are asked to define the analogical relations between the source (reality might be one case) and the consensus model. Besides, as scientists rely on models and model-based reasoning has been one of their common practices, there is a view that in science teaching, pupils should become familiar with the processes of science and the development of reasoning abilities required for model building could be one of the goals of science teaching (Gilbert and Osborne, 1980). In that case, how can a learning situation have a modelling perspective? One alternative might be that children could come to terms with the modelling process itself. Webb (1992) outlined it as consisting of six stages:

1. Identification of the area of interest;
2. Decision about the scope and purpose of the model;
3. Identification of the factors affecting the problem;
4. Construction of the model;
5. Testing of the model; and
6. Evaluation of the model by repeating steps 3 – 5 if necessary.

Then, children will develop an understanding of how the situation to be modelled works and why it works in that way (Colella, Klopfer and Resnick, 2001). One of the most explored issues concerning models and science teaching is about how and to what extent the way that models are involved in science teaching affects children's conceptual understanding (Mandinach, 1989; Snir, Smith and Grosslight, 1995; Stratford, Krajcik and Soloway, 1998; Frederiksen and White, 2000; Perkins and Grotzer, 2001; Hansen *et al.*, 2004).

If taking into consideration the three purposes of science education identified by Hodson (1993), that is, 'learn science', 'learning about science' and 'learn how to do science', then models have one more vital role to play: to teach children about the nature of the scientific models – that scientific knowledge is a human construct and that models vary in their ability to approximate, explain and predict real-world phenomena (Gilbert, 1991; Justi and Gilbert, 2002). The above three aspects of science education considered under the prism of the modelling familiarisation process do not necessarily correspond to 'independent' and diverse teaching objectives. A teaching approach might work simultaneously at more than one level and it is questionable whether it is possible for each objective to stand out from the others. Different research programs and curriculum innovations have been designed in trying to explore this issue. In the US, the ‘Model-Enhanced Thinker Tools’ (METT) curriculum was created to enable middle school children to learn about the nature of models and modelling, while improving their conceptual physics knowledge (Schwarz and White, 2005). In a similar attempt, Gobert and Pallant (2004) found out that they could promote middle and high school children’s knowledge about plate tectonics and their epistemologies of models if using a model teaching approach. Previous efforts had ended up being not so successful. When the ‘ThinkerTools’ curriculum – an earlier version of the METT curriculum – was applied, it succeeded in fostering children’s understanding of the nature and utility of models but without promoting similar gains in children’s understanding of the process of creating and evaluating models (Schwarz and White, 1998). But in this case, the children did not have the chance to build their own model from scratch (Crawford and Cullin, 2004). Carey and Smith (1993), based on their reading of studies by Smith, Snir and Grosslight (1992) and Wiser, Kipman and Halkiadakis (1988), concluded that it is very hard, if not impossible, to change children’s epistemologies even following a theory-building approach. Both had designed curricular interventions aiming to change children’s conceptions of models while fostering conceptual change in two domains respectively, the theory of matter and the thermal theory.

In the UK, one of the outcomes of the ‘Tools for Exploratory Learning Programme’ was that if children made their own models, they could better understand their nature; that a model is simplified, fallible and can be changed (Bliss, 1996). In the US as well, there are studies supporting the role that a model-centred approach could play in the development of children’s epistemological views about science (Stewart *et al.*, 1992; Penner *et al.*, 1997; Spitulnik, Krajcik and Soloway, 1999). Then, one more question that arises here is the extent to which a child’s view about the nature of the scientific models is formed, regardless of its own modelling abilities. In the end, probably one of the most integrated curriculum reforms in the US is the implementation of the ‘Model Assisted Reasoning in Science’ (MARS) curriculum development project that began in 1992 with its last phase starting in 2002. Its aim is to find out how middle school children understand and use different model forms, how and to what extent model reasoning makes science learning easier for children and how knowledge about the nature of models influences children's model-assisted reasoning skills (MARS, 2004).

Going further, why do we adults deal with modelling? Surely, not only for fun. Models can be quite helpful tools for making predictions and providing explanations of a wide range of phenomena. Thus, they play a central role in science and technology. And as our daily life becomes more and more dependent upon science and technology, models are applied to a constantly wider spectrum of activities. Boohan (2002) lists a number of models that help us to make predictions and others having an explanatory function. A scale model of an aeroplane, a dummy used in a car crash experiment, a rat used for testing medicines, a city map and a computer weather forecast model can be used as predictive tools. Physical models such as an anatomical model, a model of the sun, earth and moon and a space-filling model of a water molecule are cases of models mainly used to provide explanations.

In my research, I shall focus on the exploration of children's modelling abilities as they are expressed when children make their own models or explore models created by someone else. These models are not scientific. They correspond to situations taken from young children's everyday life, such as the planting of flowers or the dissemination of news. They are realistic, unrealistic as well as abstract dynamic models; the entities involved are objects and in the research tasks mainly qualitative and occasionally semi-quantitative reasoning are involved.

2.2.2 Modelling with computers

There are now a variety of tools able to serve modelling purposes. Amongst them, as technology makes rapid advances, computational tools have become increasingly used.

Most of the computer-based modelling tools can be used in two different ways (Mellar and Bliss, 1994). They can be used in an *exploratory* mode (also known as *simulation*), in which the user has no access to the model which has previously been defined by someone else. But, they can also be used in an *expressive* mode (also known as *modelling*), in which case the user has to construct a model from scratch. In the first case, the users may be allowed to make a few changes, such as changing the values of some of the parameters of the model. Thus, they might be able to hypothesise about the possible way the model works, the kind of analogical relations involved and at the same time confront the modeller's view of the problem. In the second case, just the building blocks are provided and the user is called on to create a model – the definition of the analogical relations is a prerequisite in this process – and run it. Here, then, users put forward their own views; and can reflect on them and on how adequately the model represents them.

In the field of science education, computer-based modelling tools have been widely recognised as valuable educational tools. Using them, children can have access to phenomena they did not have before because they are time consuming (e.g. a population change lasting for months or years), their duration is very short (e.g. a ball is hitting a wall) or they are too large or too small to be directly perceived (Buckley, Boulter and Gilbert, 1997). Thus for the very large, a mechanical device presenting the relative position of the sun, the earth and the moon and the rotation of the earth can be used for modelling seasons and day/night. At the opposite extreme, there is a 'non visible' world that now becomes accessible to children. For example, they are able to see how the digestive system works or how the particles are arranged in the different states of matter. Another aspect is the way the 'invisible' more abstract world, consisting of conceptual entities like velocity or forces, becomes more accessible through these systems. There are cases where it is not possible, for reasons of safety or cost, for children to be present while things such as laboratory activities or industrial processes take place. Furthermore, the use of tools supporting exploration and experimentation brings into the classroom a more motivated, playful, experimental, explorative and iterative way of learning (Osborne and Hennessy, 2003). Moreover, the computer models, as a particular category of models, could help children to understand better the content of science, the processes of science and possibly the nature of science (see subsection 2.2.1).

In the modelling process the role of the computer tool is a vital one. In computer science terms, during the modelling process computers are executing programs. A computer program can be defined as "*a set of instructions for carrying out operations on data*" (Fishwick, 2000, p. 3). These instructions must be provided in a specific way, using any of the available programming languages. A programming language consists of a set of symbols each of which represents a computational action or an object. Depending on how well users have mastered the specific language, they may be able to describe and predict the behaviour of the computer from reading the program (Kelleher and Pausch, 2003). The symbols a programmer manipulates can be textual (strings of words, numbers or symbols), visual (pictures or diagrams) or both. For instance, let us suppose that someone wants to design a computer model picturing what is happening in a field with foxes and rabbits, representing qualitative relations such as ‘foxes eat rabbits when they are close to each other’. One might imagine that the modeller is programming the computer merely by typing the string of words “*if a fox is next to a rabbit, then there is no rabbit next to the fox*”, though no such system of programming in natural language exists. Instead, a much more rigid and restricted textual language has to be used. Thus the problem is not text itself but the specific form of text the computer needs. An alternative simple method of programming does exist, in which the modeller programs by using graphical tools. Thus he/she could draw ‘before’ and ‘after’ pictures of a ‘fox’ removing a ‘rabbit’ from the screen. Inevitably, any computer tool (software) able to be used as a modelling tool asks for communication with the modeller in terms of a specific programming language which itself may be easier or more difficult to use.

2.2.3 Computer modelling in the curriculum

Computer modelling has been an issue in the field of education since the late 1970s (Kelly, 1984). Different computer modelling activities have been attempted in areas like design and technology, mathematics, science and geography ever since computers became common in schools in the 1980s. Today, the National Curriculum for Information and Communication Technology (ICT) in England (DfEE/QCA, 1999a) identifies four aspects in which children should make progress: (a) ‘finding things out’, (b) ‘developing ideas and making things happen’, (c) ‘exchanging and sharing information’ and (d) ‘reviewing, modifying and evaluating work as it progresses’. Issues related to modelling are included in the ‘developing ideas and making things happen’ strand. Children are expected to do the following things at the indicated levels:

- Level 1: to recognise that commonly used devices work responding to instructions;

- Level 2: to plan and give instructions to devices to make things happen and to use ICT to explore real and imaginary situations;
- Level 3: to use sequences of instructions to control devices and to make appropriate choices when using computer models or simulations for a specific purpose;
- Level 4: to use ICT systems to control events and to sense physical data, to recognise patterns and relationships in a computer model or simulation and make simple predictions;
- Level 5: to realise that being precise is an issue when writing instructions to control a device and that an ICT device can be used to control and measure external events, and to explore the effects of changing the variables in a computer model;
- Level 6: to work on sequences of instructions to control events, to modify the rules of a computer model predicting the effect of such changes and to evaluate a computer model;
- Level 7: to use ICT to analyse physical variables and control events, to create computer models and design procedures with variables;
- Level 8: to design and implement systems; and
- Exceptional level: to evaluate computer models.

According to this approach, children become familiar with the process of 'developing ideas and making things happen' focusing on two aspects of the modelling course of action. In one case, when looking at devices such as a floor turtle or a buzzer, the emphasis is on how to control their function by writing the proper set of instructions. When children deal with a computer model or simulation, the emphasis is more on the outcome of the representational process and less on the representation process itself. Amongst the schemes of work suggested for key stages

1 and 2 (QCA, 2000b), and key stage 3 (QCA, 2000a) those related to modelling form two different groups. One is about computer modelling (Year 1: an introduction to modelling, Year 3: exploring simulations, Year 4: modelling effects on screen, Year 5: graphical modelling, introduction to spreadsheets, Year 6: spreadsheet modelling, Year 7: models: rules and investigations) and the other is about controlling devices (Year 2: routes: controlling a floor turtle, Year 5: controlling devices, Year 6: control and monitoring – what happens when …?, Year 7: control: input, process and output, Year 9: control systems).

In the case of controlling devices, children are called upon to define simple procedures, as soon as they are introduced to this process for the first time during key stage 1 and as they progress through the Years, to deal with more complex devices. They start by giving instructions to a floor turtle, and they move on to control devices such as a buzzer, a window alarm, a car park barrier, or a water ride. As far as computer models are concerned, children start to explore simulations, to learn to take control over such models, to modify them and later to create their own models only when entering key stage 3. This means that an opportunity is lost for children to express themselves computationally and to see the computer as a powerful expressive tool in key stages 1 and 2. Mellar (1990) argues that this approach ignores the fact that before entering formal education children are already capable modellers. And, instead of starting from children's models and what they already know about the modelling process, children are introduced to computer modelling by exploring adults' ready-made models. Another approach sees progression in modelling as being achieved by the increasing complexity of contexts and models, both those built by children themselves and by others (Boohan, 1995a) – an alternative that was probably taken by DfEE/QCA (1999a) in the case of learning how to control devices. Activities which use both simulation and modelling could shape this approach. A child could use a simulation and by inductive reasoning conjecture the underlying principles. Then, he/she could use these principles to construct a model using it deductively to see where its suppositions lead in cases for which the simulation program is inappropriate (Dorn, 1975). Ogborn (1998) also suggests the use of modelling tools in both modes, explorative and expressive, taking into consideration the pros and cons of each mode as they emerge from the research. Systems of some complexity are proposed for explorative use while simpler ones for expressive use encouraging further thinking and abstraction.

At the same time, the use of simulation tools could introduce some dangers. In the case where children spend a long time working with them, then obstacles might be created regarding children's approach to the modelling performance. Scaife and Wellington (1993) have classified them as follows:

- Children might misunderstand how to control variables as far as industrial processes, ecological systems and laboratory experiments are concerned;
- Simulations might be caricatures of reality rather than representations of it;
- Children might confuse simulations with reality; and
- In simulations there are hidden unquestioned models, facts and assumptions.

In addition, Webb (1994), based on her studies, suggests that it is easier for children to understand the behaviour of a model if they have designed it rather than exploring a simulation. This puts forward the view that children should be encouraged to construct their own models at an early stage during the process of becoming familiar with modelling. Of course, this presupposes the existence of modelling tools suitable for use by young children in primary education.

Furthermore, the program proposed by DfEE/QCA (1999a) to be used by children to familiarise them with the computer modelling process in detail is a spreadsheet. Although the extensive use of spreadsheets in education suggests that it is a powerful teaching and learning tool and there are many applications in different subject areas, it is a tool that is not very suitable for young children. Thus, primary education and first years of secondary education children are excluded from the modelling process. They are restricted to graphical modelling, although there are modelling tools available for young children. The same tendency to rely on simulations and spreadsheets is also detected in the National Curriculum for science in England (DfEE/QCA, 1999b). Its programmes of study put forward areas where modelling has a role to play, but the suggested modelling activities are very limited and children never meet with the modelling process as part of the scientific endeavour.

In addition, in the ICT curriculum the modelling process is introduced to children, either as a way to control devices or as a way to represent situations. And it is uncertain whether children are able to anticipate that both procedures have a lot in common, being two sides of the same coin. Probably this was not one of the intentions of DfEE/QCA (1999a). In both cases, modelling is introduced as a specific technique with which children have to get acquainted, which sounds reasonable in the context of our technologically governed society. But modelling is more than that. Modelling is not only about how to make things happen but also about explaining why things happen. Not only technologically literate people use it. Ordinary people applied it well before the wheel was invented and will apply it as long as human thinking is involved. This aspect of everyday modelling is missed in the curriculum.

Nonetheless, how and to what extent modelling is involved in classroom practice, depends not only on the curriculum and the tools available; teachers have also a vital role to play. In the end they are the ones deciding when, how and to what extent modelling will play an active role in their teaching. Interestingly, the 'Science Teacher Training in an Information Society' (STTIS) project, which aimed to investigate the conditions for science teachers to command technology based tools and to successfully implement their use in their classes, found that in England the use of modelling and simulation tools in all year groups is quite limited, despite a curriculum where modelling is an issue (Stylianidou, Boohan and Ogborn, 2005).

2.3 WorldMaker and other computer-based modelling tools

The modelling tool used in my research is WM. When I started the research, there were a very limited number of modelling tools suitable for use by young children in primary education. Therefore, although the issue of comparing different modelling tools would now be very promising, this was not feasible at that time on account of the limited number of tools available. In addition, by focusing on one tool, I could focus less on the technicalities of how children learn to use it, but more on broader issues concerning children and the modelling process. Thus in my research, WM was the only modelling tool used to investigate children's modelling abilities. By now, several new modelling tools have been designed for young children, some of which are quite similar in nature to WM, whilst others differ in various aspects.

A brief description of WM alongside an example of a WM model and a short discussion of its uses are provided in subsections 2.3.1 and 2.3.2. The tools which relate in some interesting way to WM, and which have served educational purposes for children in primary and first years of secondary education are reviewed in subsection 2.3.3.

2.3.1 General description of WorldMaker

WM was given the name WorldMaker to encourage children to think that modelling is about 'making their own world', that modelling is creative (Boohan, Ogborn and Wright, 1993). Essentially, any WM model is concerned with *backgrounds* (i.e. places) and *objects* (i.e. things that can move around these places) and what they do. As the WM designers were inspired by the cell automaton invented by John von Neumann (Ogborn, 1999), the WM objects and backgrounds are placed on a grid of cells where all the action takes place. Only one object can be placed in each cell. Each cell can also have a background.

The behaviour of each *filler* (i.e. object or background) is determined by a list of rules (limited in number in some versions of the tool). These rules are defined graphically and they show the conditions and the actions to be taken if the conditions are met. Both actions and conditions are described in terms of objects, backgrounds and relations. Each rule has a 'slider bar' which determines the *probability* that it will 'fire' if its condition is satisfied. Rules may thus be 'switched off' by setting their probability to 0. In addition, when a filler has more than one rule, the modeller needs to decide on their order and the 'rule logic'. One possibility is that all of the rules of a filler are tested in turn, and for each condition that is true, that rule is 'fired' ('Try all' logic). Or, all rules are considered until one rule 'fires', after which no further rules are considered ('Do one' logic). The rules are uniform, that is, the same set of rules applies to all the fillers of the same kind. Also the actions they describe are local, that is, an object may affect or be affected by another object only if it is next to it, an object may affect a background or be affected by a background only if it is on it, and backgrounds may affect each other only if they are adjacent. WM allows specific kinds of actions for an object. These are (a) change of nature of fillers (including making new and destroying), (b) change of direction (orientation) or (c) change of position. For a background only, the first two kinds of action are allowed.

One example of a WM model is the 'para' model as shown in Figure 2.1 (Boohan, 1995b). The grid is divided into two areas. The dark area represents an area with high food concentration and the light area represents one with low concentration of food.

Each area is built up of cells having one of two different kinds of background. There is one kind of object, the paramecium. WM requires the paramecia to be objects because they need to be able to move (backgrounds do not move). All objects and backgrounds have:

i. A name (paramecium, high and low food concentration);

ii. An icon (a dot stands for a paramecium and two shaded squares each for the two kinds of background);

iii. A position on the grid; and

iv. (Optionally) a direction (in our model the paramecia have not got a specific direction of movement as they move randomly).

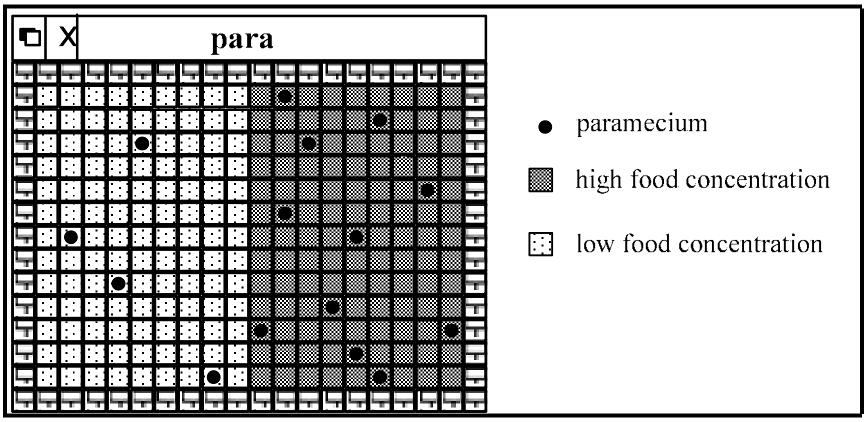


Figure 2.1 – The 'para' model in WorldMaker

When the 'para' model is running, the paramecia move on both areas (backgrounds), without causing any change to the backgrounds they are on, and without being provided with a specific direction of movement (they move randomly); they simply change position in random directions if there is an empty cell into which to move.

The rules describing the movements of a paramecium are shown in Figure 2.2.

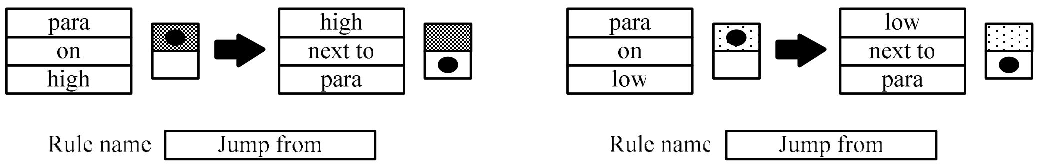


Figure 2.2 – WorldMaker rules for the 'para' model

For the paramecium to jump from a cell with high or low concentration of food, the rules must be defined so that it jumps to a cell with no specific background. The 'rule logic' applied is 'Try all'.

When the model is running, more paramecia become concentrated in the high food concentration (dark) area than in the low (light) one and they appear to move more slowly in the dark area. Even though it looks as if the dark area 'attracts' a paramecium more strongly than the light area does, the rules involve none of the possible WM background actions. Both areas neither change the nature of a paramecium nor give it a direction. Furthermore, in WM all 'speeds' of movement are the same – one cell width per unit of time, thus an action affecting the speed of movement cannot be defined in the WM software. To obtain this global behaviour in WM, since there are no global rules, we have to vary the probability of the local rules describing the movement of the paramecia from the different areas. The area with high food concentration where there is the higher concentration of paramecia and where they appear to move more slowly, is the one for which the 'Jump from' rule has the lower probability (and vice versa). This behaviour is typical of WM. An effect – here that paramecia cluster in one region rather than other – is a side effect of a different behaviour, that is, probability of moving within a region. A good question arises: Is the biology of this correct? Do paramecia really end up in nourishing regions merely because they move less often there?

Further, there is a limitation regarding the way WM rules have to be expressed. In particular, only two fillers can be mentioned in any one rule – here a paramecium and a background. The rule cannot both specify where the paramecium comes from and where it must go.

The 'para' model also exemplifies the case that in interpreting the WM models, the distinction between the 'macro' level of the phenomena and the 'micro' level of the explanations in terms of the actions performed by the participants is fundamental (Boohan and Maragoudaki, 1997).

Prof. Jon Ogborn, Richard Boohan and Simon Wright at the Institute of Education, University of London, designed the software package presented above. Nancy Law and Sandy Li at the Centre for Information Technology in Education (CITE), University of Hong Kong, later designed a modelling tool called WorldMaker (Hong

Kong) based on the conceptual design of the former software package but developed on a different hardware and software platform (CITE, 2001a). In its latest version – WorldMaker 2000 – further features are provided such as multi-player functionality, a larger repertoire of rules, parameter settings, background image support, an unlimited number of rules and objects and descriptions for rules (CITE, 2001b).

2.3.2 WorldMaker in the classroom

Learning about WM essentially falls into three stages: (a) exploring a model, (b) changing it and (c) creating a new one (Boohan, 1994). To get an idea of the familiarisation process let us consider the 'para' model presented above.

Initially, the 'para' model is given to children for exploration. There are a lot of things children can do in order to see how the paramecia behave. They can redraw the screen by changing the size and the placement of the backgrounds, and they can plot on the grid different numbers of paramecia in different places and watch how the model evolves. Thus, they could put all of them initially in either kind of area, or distribute them between the different areas. They can vary the size and shape of the two areas.

Simply altering the 'slider bars' of the rules can change the 'para' model very easily. If one of the rules describing the movement of the paramecia is set to 0 and the other to 100, then the paramecia will mostly end up in the area where they do not move at all (they all will, if the edge between the areas does not get blocked with paramecia not moving). If both rules are set to 50, then, on average, there will be equal densities of paramecia in both areas (equal numbers if the areas are the same size). Then, children could argue about a new identity they could envisage for the backgrounds instead of high and low concentration of food. Could it be light and dark areas, or perhaps dry and damp (in which case the paramecia might be thought of as wood lice)?

Children can create a new 'para' model in two ways. They can change a model that already exists. For instance, they could have a third area with a medium concentration of food, they could have a paramecium moving slowly in the area where there is low and not high concentration of food and so on. Rules can be changed (always by clicking and selecting) by altering fillers, by altering relations (‘by itself’, ‘next to’, ‘points to’ and ‘on’ for an object and ‘by itself’, ‘next to’, ‘points to’ and ‘with’ for a background), or by choosing the form of the rules from a rule menu. When children define a rule by selecting the fillers and the relations they want, WM does not change more than one object or background in one rule. Thus, it is necessary to change fillers and relations separately. For example, paramecia can move or give birth to baby paramecia but they cannot simultaneously perform both of these actions in one rule. Alternatively, children could start creating their model from the beginning, by creating new objects and backgrounds and defining new rules for them.

Tasks have been developed for classroom use in primary and secondary education that might be used to support any of the above activities (exploration, change and creation of a model). Many are related to science, for example, epidemics, predator-prey systems, forest fires, crystallisation, diffusion, radioactivity and chemical reactions. There are also models that might be used for teaching concepts in mathematics (patterns of numbers and probability), in geography (coastal erosion and formation of volcanoes) and even in social sciences (spreading of ideologies) (Boohan, Ogborn and Wright, 1993; Boohan, 1997; Ogborn, 1999).

Early trials with prototype versions of WM suggested that this tool encourages children aged 10-17 to think, to experiment and to try out their ideas. The problem ended up being how to control the flood of ideas children want to try rather than how to trigger off their thinking. There was also evidence that children are able to deal with issues about the relation between the global behaviour of a model and the local rules describing it (Boohan, 1992). When the CITE-developed versions of WM were used in secondary schools as well as in a teacher workshop, a similar tendency was identified. Furthermore, it was found that WM is a useful tool for teaching and learning abstract, difficult and hard to demonstrate topics such as radioactivity, ecology and genetics especially in group situations (Law and Tam, 1998; Law, 2004; Law and Lee, 2004).

2.3.3 Review of other computer-based modelling tools

Since the research reported here was begun, using WM, a number of other computer-based modelling tools suited to educational use have been developed. They are briefly discussed here, considering their main constructs/features together with the consequences for dealing with a model. This review aims to locate WM in terms of these modelling tools. Then, the main designing principles of WM will be highlighted and the issues explored in this research, which are related to its educational value and arise from its design, will be placed in a wider context.

The tools discussed are the following:

- AgentSheets and Stagecast Creator;
- StarLogo and Squeak;
- ToonTalk; and
- IQON and LinkIt.

Before discussing these tools, it is useful to summarise some of their key attributes that relate to WM. In AgentSheets and Stagecast Creator, as in WM, models are about objects and the actions they perform, and the actions are represented in graphical rules. In StarLogo and Squeak, models are also about objects, but the actions are represented by text. ToonTalk follows a different approach from WM. Instead of defining rules, a robot has to be trained to perform specific jobs. IQON and LinkIt by contrast deal with models in terms of variables and not in terms of objects. In both tools the variables and the relations between them are expressed in a graphical way.

2.3.3.1 AgentSheets and Stagecast Creator: models in terms of objects and graphical representation of actions

AgentSheets (Repenning, 1993) and Stagecast Creator – from now on, SC – (Smith, Cypher and Spohrer, 1994) are presented first and in more detail because they are quite closely related to WM. The elements of a model in all these are the structural units (objects), their behaviour and the grid of cells on which they interact. These structural units are called *agents* in AgentSheets, *characters* in SC and *fillers* in WM. An AgentSheets agent, like a WM filler, can occupy only one cell, but a SC character can be larger than a cell; thus in a SC model the size of the characters is an issue.

In AgentSheets, SC and WM, graphical 'if/then' or 'before/after' rules specify the interactions between the structural units. In WM (see subsection 2.3.1) and SC, the graphical rules are 'before' and 'after' pictures of the grid cells involved in an action.

In this case, the modeller is able to envisage the action just by comparing the two pictures – a potentiality expected to facilitate the use of these tools by primary school children.

To facilitate comparison the 'para' WM model presented before (see subsection 2.3.1) about paramecia that tend to concentrate in an area where there is high concentration of food, was designed using SC (see Figure 2.3) and AgentSheets (see Figure 2.4).

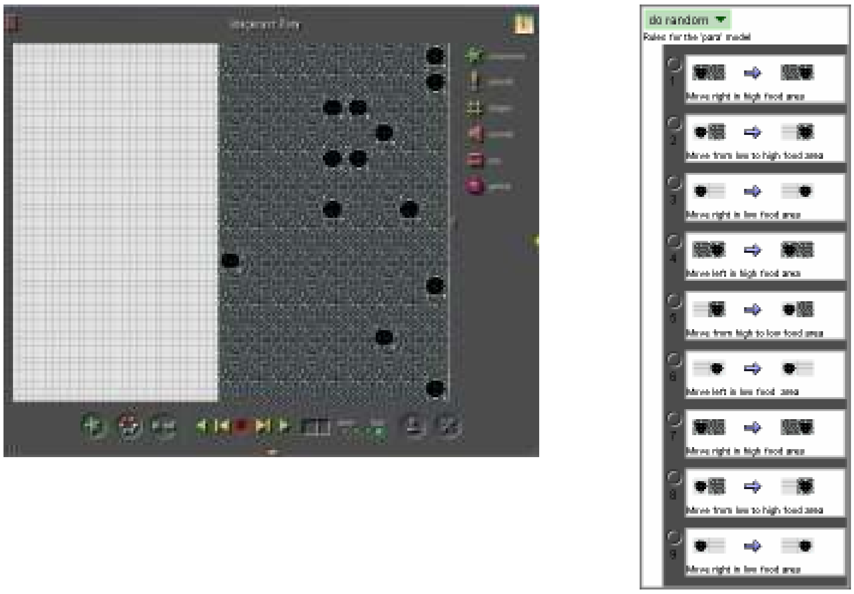


Figure 2.3 – The 'para' model in Stagecast Creator

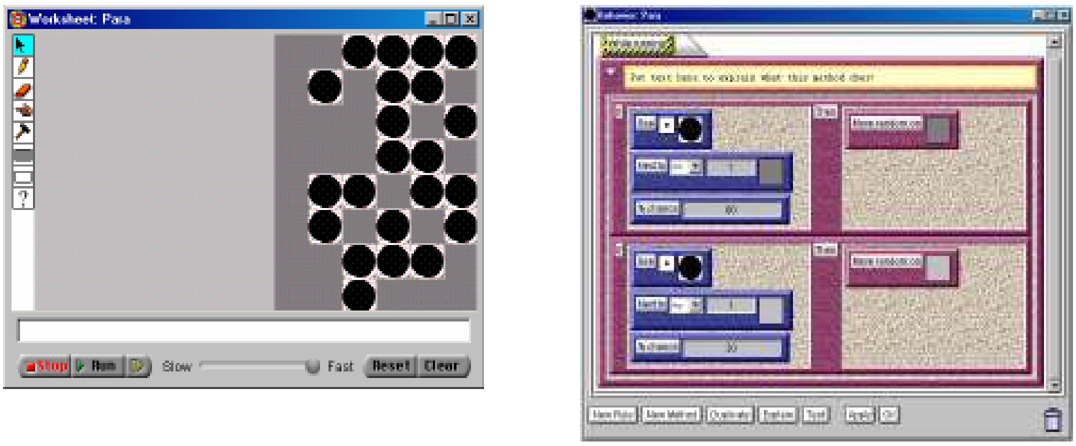


Figure 2.4 – The 'para' model in AgentSheets

The reader may notice that nine rules represent in SC what is done with two rules in WM (see Figures 2.2 and 2.3). The reason has to do with the fact that in SC there is no probability for the rules. To make the paramecia gather in the area with high food concentration, nine rules need to be defined, as opposed to two rules in the case of the ‘para’ WM model. Six different rules represent all the possible horizontal movements in both backgrounds. To make the paramecia concentrate in the area with high food concentration three of these rules describing the paramecia’s movement from left to right (in both backgrounds and from low to high) are defined twice. When the ‘para’ SC model runs, the rules defined twice will have a greater probability to be ‘fired’ than the rest of the rules. After a while the model converges on a state in which nearly all paramecia have shifted to the area with high food concentration. In contrast to being able to vary the probability of ‘firing’ a rule in WM, the need to add replicas of a rule to make it happen more often seems both artificial and limiting.

In AgentSheets the rules are very similar to those of WM, but the code used to build the model is different (see Figure 2.4). The ‘if’ and ‘then’ parts of a rule corresponding to conditions applied to agents and the actions the agents perform, respectively, do not include the grid cells involved in the actions. A combination of text and pictures is used instead.

In order to define the ‘before’ part of a SC rule, the modeller has to specify the cells of the grid to be dealt with by clicking on them; the ‘before’ part of the rule is then ready to be completed. In WM and AgentSheets, the modeller has to drag an icon in the rule definition window instead of selecting a region of the grid. Regarding the ‘then/after’ part of a rule, if, for instance, the modeller wants to move the paramecium to the right, then in the ‘after’ part of the SC rule he/she has to drag the paramecium with the mouse to the right. For comparison, in WM he/she has to make ‘empty’ the cell in which the paramecium previously was and put a paramecium in the previously empty cell next to it. The designers of SC call it “... *analogical programming: the actions performed are analogous to the desired effects*” (Smith and Cypher, 1999, p. 212) and they applied it to make programming more like children’s thinking. On the other hand, in SC, children might approach the concept of a rule as describing an action which takes place once instead of being executable whenever and as many times as the rule’s conditions are satisfied. Then, children use SC as an animation rather than a modelling tool (Carmichael, 2000).

In AgentSheets and SC, more than one action or condition can be included in a single rule. For instance, the modeller can decide to describe in one rule the activity of burning down a tree in the cell next to the right, jumping over a building and then burning down the trees in the next five cells, if there is a tree next to the fire and the ‘energy level’ of the fire has a specific value. In a SC rule as well, an action can be depicted in more than two neighbouring cells whilst in AgentSheets and WM only the contents of a pair of adjacent cells can interact.

In all three tools, the condition of a rule can be related to the position of the fillers/characters/agents. But a SC character, as opposed to an AgentSheets agent and a WM filler, does not have a direction. In addition, in AgentSheets and SC the ‘if/before’ part of a rule can be about a condition related to the value of a variable. For AgentSheets, conditions can also be related to a mouse event, the comparison of values of two formulae or the ‘speaking’/‘not speaking’ condition of the agents in the neighbouring cells (i.e. whether they produce a sound).

As far as actions are concerned, all actions performed in WM are common to the other tools. SC and AgentSheets also allow the production of a sound or the calculation of a numerical value, with AgentSheets having a wider spectrum of actions; for instance, opening up a web page or sending a message to an agent in a cell.

WM, AgentSheets and SC are based on autonomous structural units (objects) communicating in a two-dimensional grid-based ‘world’. They use graphical rules that present concrete examples to demonstrate how the system should behave under specific conditions. This approach to modelling has two limitations (Myers, 1998). One is that it is difficult to generalise rules for complex situations; and the other is due to the fact that the grid prevents modellers from implementing interesting natural phenomena that require continuous movement such as velocity.

AgentSheets has been used to create simulations in a variety of disciplines including computer science, environmental design, fine art, robotics, music and biology for a wide age and expertise range of modellers; from primary school children to NASA scientists and the common public. A number of studies have been designed exploring the use of AgentSheets in different learning contexts. Cherry *et al.* (1999) focused on the issue of integrating simulation activities with other activities (hands-on, research, discussions) and found out that primary school children (aged 8-11) were able to explore and create models about biological concepts such as populations and ecosystems as well as historical ones. In a different study, middle school children (aged 11-14) were found to be able to explore ecological simulations involving ideas of metabolism and energy consumption, eating and reproducing (Craig, 1997). In the framework of the 'Educational Software Components of Tomorrow' (ESCOT) project, middle school children used AgentSheets to learn about the derivation of the mathematical constant π (Repenning, Ioannidou and Zola, 2000). Ioannidou, Repenning and Zola (1998) also considered the effectiveness of simulation/modelling as a teaching method in social studies asking high school children to create models about historical events. In the above cases, AgentSheets was used in a classroom setting from primary to secondary level to teach science, maths and history, although it seems to be a modelling tool more suitable for adult modellers (Kindborg, 2003) – it contains more programming constructs than SC and WM and the syntax of the rules is rather more complicated.

KidSim – a prototype version of SC – was used in the 'Science Theater/Teatro de Ciencias' (sTc) project by primary school children from 2nd up to 5th grade, as part of their science curriculum (Rader, Brand and Lewis, 1997). The youngest children explored questions such as "*Would flowers grow in space?*", and one of the topics investigated by the eldest was the formation of blood clots. One more small-scale study (Louca *et al.*, 2003) emphasises the use of SC as a modelling tool in science. Fifth grade's children were found to do twice as much planning but half as much debugging when they used SC, compared to children using modelling tools requiring them to write textual code. In a different study, middle school (7th grade) children worked with SC in structured activity sequences and were successful in developing modelling skills and conceptual understanding regarding the concept of light (Louca and Constantinou, 2002).

2.3.3.2 StarLogo and Squeak: models in terms of objects and text-based representation of actions

StarLogo and Squeak models are about objects, as are those in WM, AgentSheets and SC. However modellers have to define the objects' behaviour by writing text instead of using graphical rules. The reason I decided to discuss StarLogo and

Squeak, instead of LOGO, is because they represent a more modern approach to textual programming of objects. Moreover, both tools can stand as representatives of turtle graphics – a characteristic of LOGO.

StarLogo

StarLogo (Resnick, Bruckman and Martin, 1999) was designed to help students to explore the behaviours of decentralised systems such as ant colonies and traffic patterns. Modellers write simple rules in a text form that control thousands of objects and observe the patterns of behaviour. These patterns arise without centralised control and are determined by the local interactions among the objects. Using StarLogo to make models from individual objects, children are enabled to develop a better understanding of the models' global behaviour (Klopfer, Colella and Resnick, 2002). That is true for WM as well, although in WM the global behaviour of a model is also affected by the rules' settings.

StarLogo is an extension of LOGO in three ways (Resnick, 1995). First, a StarLogo modeller controls many more *turtles*. In addition, the StarLogo turtles interact with each other and with the background on which they move. Third, the background on which turtles move in StarLogo is divided into *patches*. Patches have many of the turtles' capabilities such as being able to execute StarLogo commands.

Children have made a number of StarLogo models for a variety of situations such as a traffic jam, a termite construction and predators and prey (Resnick, 1999).

Squeak

Squeak (Kay, n.d.) was designed for children and allows modelling with objects called *morphs*. Modellers are able to choose from a variety of predefined objects or to design their own. Morphs have the capabilities of a LOGO turtle. They have a direction, they can move forwards or backwards and they can turn right or left. The instructions are given in a simple text-based computer language (e.g. 'forward 10'). There is no use made of the idea of analogical programming, in which actions needed to generate a rule correspond closely (visually and/or in action) to the desired effect. In the same way in AgentSheets, the model representation is different from the run time representation. Squeak allows the modeller to define the actions of an object by simply choosing from a predefined list of commands, whilst in StarLogo he/she has to type in the text of the model. In Squeak, the modeller has to drag the predefined command (i.e. *tile*) into the rule definition window, and so to build the model. Morphs can change their position, size, orientation and appearance, and they can play sounds. Besides, in Squeak the modeller is able to define simple conditions for the actions.

A variety of projects, created by children and young people from primary school to university level, can be found in Squeak (n.d.).

2.3.3.3 ToonTalk: creating models by training a robot

ToonTalk (Kahn, 2001a; Kahn, 2004) is a programming language suitable for very young children. A ToonTalk programmer works in an object-oriented environment. But instead of using commands (as in the case of StarLogo and Squeak) or writing graphical rules (as in WM, AgentSheets and SC), he/she can use a set of animated objects to train a robot to execute specific actions in a virtual animated 'world'. However, there is a considerable amount of metaphor to be learned.

The ToonTalk 'world' is presented as being similar to a city. There are trucks, helicopters, houses, bike pumps, toolboxes, vacuums and robots, each with a specific type of programming use. There are also birds and nests. One fundamental idea behind ToonTalk is that every computational aspect is mapped into a concrete metaphor. For instance, a computation is a city, an active object or agent is a house, a method or clause is a robot, birds carry messages between the houses and so on. Questions could be asked about whether the metaphors are well chosen, and about their number.

The programmer controls an animated person in this video 'world' to construct, run, debug and modify programs. At the start-up of the tool, a helicopter arrives at the city, the animated person is taken from the helicopter and the programmer tells her what to do. She is followed by a dog, which carries tools that may be needed in programming.

The animated person can accomplish a variety of tasks such as copying an item by using a magician's wand, generating a new process by dropping a box and a team of robots into a truck (which drives off to build a house), terminating a process by setting off a bomb, performing simple operations such as addition by building a stack of numbers (which are combined by a small mouse with a hammer), sending a message by giving a box or a pad to a bird, or changing a data structure by taking what is in a box and putting in new objects. She can train a robot to achieve specific tasks by entering its ‘thought bubble’ and showing it what to do using standard ToonTalk tools. The trained robot along with its input box can be attached to the back of an object to give it functionality. Figure 2.5[1] below shows how ToonTalk programs are constructed.

Figure 2.5 – A robot is being trained to double a number

Another important feature of ToonTalk is that the actions performed by the robots can be easily generalised by removing detail, so that they can be applied in a wide variety of contexts. Thus a robot can be trained initially how to double the number one, and then it will easily generalise the mechanism to double any number. As in WM, SC and AgentSheets, the programmer writes rules in graphical form, which are general statements of what the objects are able/trained to do if the rules’ conditions are satisfied.

Kahn (2001b) claims that ToonTalk is a tool that has been designed to be appropriate for a wide age range of programmers. Children, as young as 5, can master the full set of ToonTalk elements, while university students can use it to explore and visualise areas such as concurrent algorithms.

[1] As shown in Kahn (2004, p. 3)

In the ‘Playground’ project[2] a number of studies explored the use of ToonTalk to enable young children to build their own video games as well as collaborative game design. In doing so children learned how to play with rules to make their own computer games. Children as young as 4 and 5 years old were found to be able to use some basic elements of ToonTalk to program the robots, and they could cope with a simple generalisation technique (Morgado, Cruz and Kahn, 2001). Working with older children (aged 6-8), Hoyles *et al.* (2001) found that after programming with ToonTalk the children became more aware of rules. These rules fall into three groups: (a) “*Player rules – a regulation that must not be transgressed ...*”, (b) “*Player goal – a maxim or formula that is generally advisable ...*” and (c) “*System rules – a generalised statement that describes what is true in most or all cases ...*” (pp. 2-3). Moving further, working with children aged 7-8, they came to the conclusion that the expression of formal rules was shaped by the kind of the task the children responded (predictive, descriptive or explanative), the narrative context of the game (whether or not it does ‘make sense’) and the means of expression (computational, spoken or written). Other studies suggest that the shift from narrative to formal rules seems to be encouraged by a collaborative setting when there is no face-to-face interaction (Adamson *et al.*, 2002; Noss *et al.*, 2002).

A new European project called ‘WebLabs’ explores the use of ToonTalk in science and mathematics (Kahn, 2004). In the area of mathematics, ToonTalk has already been used as a teaching tool. For instance, Mousoulides and Philippou (2005) explored in a case study the way ToonTalk could be involved in teaching mathematical concepts to 13 years old children.

2.3.3.4 IQON and LinkIt: models involving variables

In the professional modelling process for science and engineering, it is common to build models using variables rather than objects and their actions. This therefore represents an approach to modelling that differs substantially from that of WM and most of other tools discussed above. IQON and LinkIt are two tools which support this approach for young children.

[2] http://www.ioe.ac.uk/playground

IQON

IQON (Interactive Quantities Omitting Numbers) (Miller *et al.*, 1991) is a modelling tool using two kinds of primitives. These are (a) continuously-valued variables or *boxes* that can take a range of values above or below a ‘normal’ level and (b) ‘negatively’ and ‘positively affects’ *links* to represent relationships between the variables and which imply incremental change. Thus, for constructing a model the modeller does not have to define the relationship between the variables in algebraic terms, only the direction of change. This is a task that can be carried out even by children in the final years of primary education (Miller *et al.*, 1993).

LinkIt

LinkIt (Sampaio, 1996) is an extension of IQON with a wider range of types of variables and relationships between them. It also uses the metaphor of boxes as variables and links as relationships. There are two different kinds of variables, smooth and on/off variables. Smooth variables are used to represent any factor that can be thought of as like a continuous variable (e.g. how rich, or how tired you are) for which ‘more’ or ‘less’ of it is meaningful. On/off variables have only two values being used to represent such variables as the state of a switch. Their main use is to represent conditional factors that can control the behaviour of dependent variables. In addition, there are two different kinds of relationship: (a) a ‘go together’ relationship where the value of the affected factor is immediately calculated based on the value of the casual factor and (b) a ‘cumulative’ relationship where the value of the causal factor can be seen as a rate of change of the dependent factor.

LinkIt has been shown to have promise as a potentially valuable modelling tool for children aged 13-18 (Sampaio, 1996).

In addition to IQON and LinkIt, there are also other tools which define models in terms of variables, but which are suitable only for older children. They use some algebraic way to define variables and relationships, often in a way close to Basic. One of the most well known is STELLA (Richmond, 1987) which, like IQON and LinkIt, uses a graphical way to represent variables and the relations between them. However, in addition, the modeller still has to type in the necessary variable assignments. The graphical representation merely guides this process. Another tool is

Modellus (Teodoro, 2002), in which, unlike STELLA, the modeller has no language to learn. He/she can write mathematical models, almost as one would on paper. Two essential features of Modellus are multiple representations and direct manipulation. Furthermore, in a European research project, a new modelling learning environment, called ModellingSpace (Dimitracopoulou *et al.*, 1999), was designed for primary and secondary education children (aged 11-17). One of the innovations incorporated in its design is that it allows the incorporation of different categories of models (quantitative, semi-quantitative and qualitative) in a simplified and synthetic mode.

2.3.4 Overview: main issues

This review has drawn attention to a number of points that are important in deciding the use and potential value of a modelling tool:

- Any modelling tool has some ‘educational overhead’ in that the working of its interface, and the way in which it specifies models have to be learned.
- A modelling tool can be used to teach modelling for its own sake as well as to support the teaching in other areas of the school curriculum such as science, mathematics, history or geography.
- As far as availability of tools is concerned, computer modelling can be an issue even in the first years of primary education. The presented modelling tools for young children can be used in secondary education as well, facilitating and integrating children’s training on models and modelling.
- In order to decide amongst the presented tools which one to use and when, a few questions might be helpful: What is the nature of the situation represented (static or dynamic)? What is the nature of the entities involved (objects or variables)? How actions are defined (graphically or textually)?
- The age and previous knowledge of children (particularly in mathematics) is a critical factor in choosing between modelling tools. Models based on objects are designed to be more accessible to younger children and less mathematically minded users, than models based on variables and relations between them.
- Dealing with object-based models, children have to define actions graphically or textually. In the graphic mode, in order to build a model, they have to draw the

rules representing all the actions as well as the necessary conditions of the actions. The repertoire of rules offered by different tools varies considerably.

- Relations between variables may be approached without first requiring uses of formal algebraic relations, through use of graphically defined model structures. However types of relation still need to be defined, and to be learned in order to build models.

- The 'same' physical phenomenon, such as paramecia's tendency to concentrate in an area with high concentration of food, may be modelled in different styles by different tools. Each style has advantages and disadvantages.

2.4 Computer modelling and natural reasoning

> "*Good modelling tools will present learners with structures that helpfully allow their thoughts to find expression. In addition, these structures, if they are well chosen, and provided that they are internalised by students, can be of value as tools for thought in other situations.*"
>
> (Bliss, 1994a, p. 31)

Looking at issues of knowledge structure and its representation in a computer program, two approaches amongst others could be considered. The first is that of Piaget and the other comes from work in the mental models tradition. Piaget's interest was in identifying the tools for thought employed in the process of knowledge acquisition, what he called *schemes* (Bliss, 1994b). In the mental models' realm, two different schools of thought have been formed. de Kleer and Brown (1983) focus on the content of thinking about simple physical systems or devices. They advocate the idea that the mental model of a physical device is about the representation of the components of the device and of how the components causally interact, the envisioning of the function of the device and the running of the casual model to produce a specific behaviour for the device. Johnson-Laird (1983) who proposes the existence of mental models that are structural analogues of the world represents the other approach. He states, "*mental models can contain tokens that correspond to entities in the world and the properties of these tokens as well as the relations between them correspond to our conception of the state of affairs that the models represent*" (p. 422). Comparing the above approaches, Bliss (1994b, 1995) says that Johnson-Laird is like Piaget in focusing on the tools of thought rather than on the content of thought as de Kleer and Brown do. Johnson-Laird differs from Piaget in that reasoning with mental models is done by manipulating tokens and searching for examples and counter-examples, and not by using logical proof. But both focus on the role of representations as a constituent of a mental model.

In my research WM was used to familiarise children with models and modelling. An obvious question is whether children can be expected to be able to cope with the basic elements of the program. According to Ogborn (1999), "*Piaget's great merit, […], was that he was the first to characterize […] the mode of thinking that he called "concrete operational". It is, simply, thinking done using imagined objects and events. Piaget saw it as characteristic of children between about 5 and 15 years of age; […]*" (p. 7). Thus, computer-based modelling tools like WM in which children tells an object, rather than a variable, what to do or what has been done to it might well be expected to be meaningful to children of primary and early secondary education – my target group.

In addition, as the computer demands formality in expression, it is vital for a modelling tool to ask for definitions of events in a way that children can cope with. In WM, events are defined in terms of pictures of 'before'/'after' rules. The understanding of a rule presupposes that children are able to see a transformation as an action on an initial state to produce a new one. It is the children's Piagetian schemes which permit them to understand this (Bliss, 1994b). My research investigates whether children of the specified age range (10-14) can cope with a WM rule and thus whether they possess the corresponding schemes. According to Bliss (1995) these schemes have a physical rather than logical nature and it is expected that "*... gradually such schemes would abstract some of the features common to many physical situations, but they would also contain the constraints of particular situations*" (pp. 18-19). In my research I shall also examine whether the schemes children posses allow them to look for common structures to describe different situations.

In computer modelling, one way to attribute behaviours to objects is to define qualitative rules. To the question "*Are children of this age range able to cope with the concept of a rule?*" Piaget (1932) would say that after the age of 10 children are already interested in the rules themselves. They can codify rules and they are able to modify the rules of the games they play (e.g. playing marbles). On these grounds, in the research, it might be expected that children would not have difficulty in appreciating the fundamental fact that WM fillers operate according to a set of qualitative rules and accepting that they themselves can define the rules.

2.5 Models, modelling, modellers and WorldMaker

> "*To create a world, whether constituted of variables or of objects, and to watch it evolve is a remarkable experience. It can teach one what it means to have a model of reality, which is to say what it is to think. It can show both how good and how bad such models can be. And by becoming a game played for its own sake it can be a beginning of purely theoretical thinking about forms.*"
>
> (Ogborn, 1992, p. 112)

In the process of science, structures have a vital role to play. Being usually depicted in a model, they are fundamental to an understanding of phenomena (Glynn *et al.*, 1989). Scientific theories attempt to provide common structures for explaining a variety of phenomena. The larger the number of phenomena explained the greater the value of the theory. Thus, structures are one of the protagonists in the scientific scene and consequently in human thinking, learning and understanding. In addition, students often fail to be acquainted with the fact that "... *physics encompasses a coherent conceptual framework and tend to believe that it constitutes a loose collection of unrelated concepts and theories*" (Papadouris and Constantinou, n.d., p. 6). According to Gilbert and Osborne (1980), one of the difficulties children experience when models are involved in science teaching is that they find it hard to apply a given model in different contexts.

It follows that a key issue in understanding models and modelling in science is the understanding of structures. Since the making of a model asks for definition of its structure, leaving aside what is non-relevant, a specific kind of structure can be assigned to each modelling tool. And the evaluation of this tool is incomplete without exploring how users and prospective modellers cope with the way structures are defined and whether they can identify apparently disparate phenomena which share a common structure. For instance, that a fire is very similar to a rumour; that a forest fire spreads from one tree to another much as a rumour spreads from one person to another (Maragoudaki, Boohan and Ogborn, 1997). This is important, as it lies at the heart of early scientific learning (Murphy, 2003), and is a step in the direction of looking at the world in a unified way; it is the beginning of theoretical thinking.

In my research, the computer-based modelling tool used (WM) uses a symbolic and abstract visualisation to represent structures. It is evaluated along two lines. Firstly, whether children can cope with the elements it provides for making the structures of models – objects and rules – and whether they use structures to identify similarities and differences. A third issue, less related to the tool itself, is also explored, namely children's attitudes towards the relation between models and reality.

CHAPTER 3

The Research Questions

3.1 Introduction

WorldMaker (WM) was designed to make computer modelling accessible to quite young children. At the time this research was begun, it had not been tried at all with young children. It was therefore an open question whether they could use it and profit from it in any way. For these reasons, the research focused on children in the age range 10-14 as the youngest age at which it seemed plausible that WM might work.

For the same reasons, a preliminary study (see Chapter 4) was conducted on a small scale with very young children, essentially to see whether it was worth going further. At that stage, the basic question was very simple: "*Could these children succeed at all with WM?*". Specifically, in the preliminary study the research questions are:

a. Are children able to use WM? (PS-RQ-a[1])

   1. Are all of the tools recognisable? (PS-RQ-a1)
   2. Do children think easily in terms of fillers (i.e. objects or backgrounds) and events? (PS-RQ-a2)
   3. Can children understand and define rules? (PS-RQ-a3)
   4. Can children work on the probability of a rule? (PS-RQ-a4)

b. What might be the nature of the tasks and situations that children can use? (PS-RQ-b)

The results of the preliminary study were very encouraging regarding children's ability to use WM in a number of modelling activities and I proceeded with creating my main research framework.

[1] PS: Preliminary Study, RQ: Research Question, a: Numbering

3.2 Main research issues

For children to engage with computer modelling several things are necessary: they must learn how to control and understand the working of a particular modelling tool; they must see how particular real situations can be represented in the ways offered by the tool; and they must be able to interpret the outcome of running the model in terms of the situation modelled. My research was designed to look at all these aspects.

Thus, the general research questions need to concern children's engagement with:

i. Learning to use WM;

ii. Thinking about situations as potentially able to be modelled;

iii. Building or using computer models of various situations; and

iv. Interpreting or evaluating computer models when run.

One other feature of modelling is also essential: models in a given modelling tool always *simplify* the situation modelled, leaving out 'inessentials'. An example of this is a model of the breeding of rabbits. In reality, the breeding of rabbits is about a male meeting a female, the female becoming pregnant, the female giving birth to baby rabbits, the male and the female looking after the babies, the babies growing up, and finally themselves breeding new rabbits. This complex sequence may, in a model, be reduced as far as simply having a rabbit create a new rabbit alongside it which is at once able to breed.

In the research, a particular device was used to help bridge the gap between complex real situations and simplified ones able to be modelled using WM. Situations were presented to the children as brief scenarios, namely *stories*. They simplify the situations so as to make it easier to see how a model might be constructed. An example of such a story is:

> "*Healthy people can catch a cold when they meet other people who already have a cold. Eventually people with colds get better.*"

This story brings out just certain 'essentials': infection of a healthy person by meeting a person with a cold, and recovery after some time. Without quite saying so, it suggests that the model needs two objects, healthy persons and persons with colds, and that rules might be that a healthy person can 'become' a person with a cold if next to a person with a cold, and that in addition, persons with a cold can turn into healthy persons on their own.

From the above discussion, a number of broad areas were identified as needing to be addressed in the research as a whole:

i. Creation of a model – constructing a story in a way that can potentially be represented as a model, and representing the story using the tool's resources;

ii. Description and explanation of a model's formal behaviour – including observing patterns on the grid and making predictions about the model's behaviour;

iii. Interpretation of the meaning of a model – considering the relations between models, stories and the real world; and

iv. Exploration of a model – either by varying the starting conditions or the structure of the model.

These areas correspond to different activities that a modeller can perform using a specific modelling tool.

Any particular modelling tool imposes its own special requirements on the modelling process. In particular, with WM, it is necessary when modelling a situation, to break it down into one or more actions and then to present each elementary action in the form of a rule. Many problems children have with modelling are related, either to the task of breaking a situation into discrete actions, or to the task of presenting each action as a rule. The first is a problem of general interest as it applies to modelling in general, regardless of the tool that is being used. The second is related to the specific modelling tool and to others (like AgentSheets and Stagecast Creator, see subsection 2.3.3.1), which ask for definition of actions in the same way. Children's performance on both kinds of tasks was explored during the research.

3.3 General research questions

The general research questions applying to the research as a whole are the following:

a. Can children understand, use and think about models in a WM form? (GRQ-a[2])

b. Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules? (GRQ-b)

c. How do children see the relation between models and the real world? (GRQ-c)

The research was not designed to investigate whether children enjoy WM nor whether to evaluate WM as a teaching or learning tool for specific subjects – answering questions like "*Do children learn any science with it?*". For this reason the situations chosen required mainly common, everyday reasoning, in areas such as breeding, hunting, transmitting diseases or spreading news. WM was the tool the children were asked to use to explore these topics and express their own understanding of them. Thus the question does not arise whether, in these cases, WM was a useful and helpful curriculum tool. Nevertheless, my research findings may throw some light in this direction.

3.4 Specific research questions

The specific research questions applying to the first and the second main studies are presented below.

3.4.1 First main study (Chapters 5 and 6)

The first main study focused mainly on the initial learning and use of WM. A strategy devised by the designers of WM and me for introducing WM via a board game was to be tested.

The research questions are:

a. Can children be effectively introduced to WM by playing a board game? (FMS-RQ-a[3])

   In this game the children were being asked to learn about WM before using it. They had to play games according to rules of WM type, to replace objects in a rule and to create their own rules.

[2] GRQ: General Research Question, a: Numbering

[3] FMS: First Main Study, RQ: Research Question, a: Numbering

Having regard to the particular features of WM:

b. Can children read WM rules? (FMS-RQ-b)

    1. How often do they think of the conditions?
    2. Do they read the rules locally or globally?
    3. According to them, do the 'before' and 'after' pictures of a rule show the same cells and do the objects in the 'before' picture interact with each other?
    4. How do they understand the relationship between rules given as a pair?
    5. Do they pay the same attention to different actions?
    6. Are there variations in the difficulties of reading different WM rules?
    7. How do they combine 'abstract' rules to make a story?

c. Can children see the relation between global behaviours and WM local rules? (FMS-RQ-c)

    1. Can they account for the overall global effects from the nature of the rules?

d. Can children replace objects in a WM rule? (FMS-RQ-d)

e. Can children draw WM rules for a stated situation? (FMS-RQ-e)

    1. Does increasing the number and kind of action in a rule affect how well they can manage to represent it as a picture?

f. Can children create WM rules? (FMS-RQ-f)

    1. What kind of actions do they tend to define on their own?

g. What do children decide in terms of 'possible'/'impossible' WM rules? (FMS-RQ-g)

    1. What reasons do they give for whether rules are 'possible' or 'impossible'? Is this related to the kind of actions considered ('realistic' or 'unrealistic)?

The first main study was mainly about the first two general research questions (GRQ-a and GRQ-b). The relation between models and the real world was explored, but only in the limited context of asking children to decide about 'possible' and 'impossible' WM rules. The study was also designed to respect the peculiarities of the way WM does its job. For instance, in WM, questions arise about the relationship of the local behaviour of objects to the global behaviour of a set of such objects, so this relation of the local to the global needed to be built-in to the questions.

3.4.2 Second main study (Chapters 7 and 8)

In the second main study the second (GRQ-b) and the third (GRQ-c) general research questions were explored to a wider extent than the first one (GRQ-a).

Its aim was to explore the following research questions, about more elaborated uses of WM:

a. How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions? (SMS-RQ-a[4])

b. How do children compare situations? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-b)

c. How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-c)

d. How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-d)

e. How do children compare participants? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-e)

f. How do children compare rules? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-f)

g. Given a set of purely 'abstract' rules, how do children predict whether outcomes are possible or not? (SMS-RQ-g)

[4] SMS: Second Main Study, RQ: Research Question, a: Numbering

h. Is children's tendency to look for actions and conditions of actions related to the nature of the situation considered? (SMS-RQ-h)

i. Is children's tendency to look for actions and conditions of actions related to the kind of question to which they respond? (SMS-RQ-i)

j. Can children draw WM rules for a stated situation? (SMS-RQ-j)

k. Can children understand and use rules in abstract form? (SMS-RQ-k)

l. What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them? (SMS-RQ-l)

m. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful? (SMS-RQ-m)

n. Can children create a WM model using WM objects and rules? (SMS-RQ-n)

A sequence of tasks, involving learning and research tasks, was devised to address these questions, as described in Chapter 7.

3.5 Overview

The research stages progress from very basic questions about first getting to grips with WM (preliminary study) through checking the learning and use of WM on a larger scale (first main study) to, in the end, examining some quite deep issues about the nature of modelling and the relation of models to the real world, as understood by children in the context of this particular modelling tool (second main study).

The aim throughout was to set the research in fairly normal classroom contexts, using activities that were plausible to think of as useable by a teacher, even though they were designed for the purposes of the research. In consequence, there is no simple one-to-one correspondence between the elements of the tasks and the various research questions. Instead, the tasks were constructed so that aspects of each question were addressed as seemed appropriate, and normally more than once.

It might, at first, seem that the research could be reduced to the simple question "*How well does WM work with these children?*". But, although this question motivates what was done throughout, it was clear that it needed to be broken down, as above, into a rather large number of narrower questions, and at a variety of levels, from the machinery of the modelling tool to the nature of models and reality. In the end, taken as a whole, answers to these questions offer some possibility of both deciding on the value of WM as a whole, and of detecting particular difficulties and issues with it that need, if possible, to be resolved.

CHAPTER 4

The Preliminary Study

4.1 Introduction

This chapter is about the preliminary study of my research. It presents the research questions, the tasks, and the study's structure and outcomes.

4.2 Formulating the research questions

When this preliminary small-scale study took place, nobody had used WorldMaker (WM) before in a systematic way, so there was no indication of the kind of problems that children might have in using it in a classroom setting. Thus its aim was to identify, on the one hand, some difficulties and possibilities children might have when working with WM, and on the other, possibilities for kinds of tasks that might be used with it.

The research questions investigated were:

- Are children able to use WM?
  Are all of the tools recognisable? Do children think easily in terms of fillers (i.e. objects or backgrounds) and events? Can children understand and define rules? Can children work on the probability of a rule?
- What might be the nature of the tasks and situations that children can use?

Thus, the results of the preliminary study were expected to be helpful for the formulation of the general research questions and for designing the research tasks of the first and the second main studies.

4.3 Constructing the tasks

Six research tasks were administered to the children (see Appendix B). Only two ('Shark' and 'Aliens'[1]) were designed specifically for the research – the WM designers had constructed the rest ('Bounce', 'Glue', 'Shopping' and 'Rabbits').

---

[1] This name was given by the children when dealing with the task

The tasks needed to address the following features:

- o Evaluation of the WM interface in terms of basic WM commands, like plotting and removing fillers, giving directions to fillers, stopping and running models, opening the rules of a filler and changing the probability or the definition of a rule; and
- o Evaluation of WM, as far as different modelling activities are involved – description, explanation, interpretation and exploration of the behaviour of WM fillers as well as creation of fillers with desired behaviours.

At the same time tasks should introduce WM to children. Thus two issues were taken into consideration. Tasks should deal with situations familiar to children and they should also progress in difficulty and complexity. Therefore, in the tasks, well-known fillers like bouncy balls, glue tubes, shoppers, rabbits and foxes, sharks and fishes perform actions such as 'movement', 'creation' and 'destruction' of other fillers on the grid. In addition, WM was used on three different levels across the six different tasks. In the beginning, the children were given fillers, which had already been created ('Bounce' and 'Glue'). Then, the children had to modify the behaviour of fillers by changing the settings (i.e. probabilities) of their rules ('Shopping') and finally they created entirely new types of fillers by building new sets of rules ('Rabbits', 'Sharks' and 'Aliens'). The last three tasks were the only ones asking children to focus on the definition process of a WM rule. In the final task ('Aliens'), the children decided themselves about the event to be modelled – the fillers participating and the kind of actions they perform.

Furthermore, the tasks, except the 'Aliens' one, had a specific subject of the National Curriculum for geography (DES, 1991), mathematics (DES/Welsh Office, 1989a) and science (DES/Welsh Office, 1989b) from which they were drawn and a specific focus, as shown in Table 4.1.

	Geography	Mathematics	Science
'Bounce'		Patterns of numbers	
'Glue'	Behaviour of materials		
'Shopping'		Probability and probabilistic behaviour of a model	
'Rabbits'		Probability and probabilistic behaviour of a model	Predator-prey relationships, ecological equilibrium
'Sharks'		Probability and probabilistic behaviour of a model	Predator-prey relationships, ecological equilibrium

Table 4.1 – Presentation of the preliminary study's tasks in terms of specific subjects of the National Curriculum

4.4 Organising the study

The study was carried out with three children (two girls and one boy) from Year 6 (aged 10-11) in a junior school in the London area. Children of this age were chosen, because according to the National Curriculum for technology (DES/Welsh Office, 1990) that applied at the time of the study, pupils had to start dealing with modelling at level 4 of key stage 2. According to the teacher, the children were of average ability and were interested in computer work. They had a little experience of using the Archimedes computer.

During the first session, I spent about thirty minutes with the children trying to get them familiar with the fillers, the grid and some of the WM tools. In the rest of this session and in three further sessions (between thirty and ninety minutes each), the children were given the program disc and a sheet giving the tasks for that session. A second sheet with instructions for using WM, created by the WM designers, was also provided (see Appendix A). Table 4.2 shows how the sessions were organised.

The children took it in turns to read the instructions, to operate the computer and to write down their answers. They were supposed to work as a group, but they could also put questions to me as the interviewer, and I became involved whenever I regarded it as necessary. The four sessions took place at weekly intervals.

Session	Tasks	Duration
1st	‘Bounce’ & ‘Glue’	90 min
2nd	‘Shopping’ & ‘Rabbits’	90 min
3rd	‘Sharks’	90 min
4th	‘Aliens’	30 min

Table 4.2 – Presentation of the preliminary study’s sessions

4.5 Analysing and presenting the children’s responses

The data collected were of two different kinds: (a) the children’s written responses and (b) the tape-recorded discussions that the children had with each other and with me (the interviewer) while doing the tasks. All the sessions were tape-recorded as the focus of this study was on exploring every aspect of children’s thinking and understanding when modelling with WM rather than on investigating specific issues related to modelling with WM. An oral description of the children’s written responses was included in the transcripts. Thus, the data used in the analysis came from the transcripts; the children’s written responses were used to clarify the transcripts when necessary.

The analysis of the transcripts proceeded in two stages. First, the transcripts were segmented into units, each unit corresponding to one kind of action or thought by the children. Then all these units were looked at, deciding which features of them were both important and possible to code. This process ensured that every part of the transcripts had been examined and described in a uniform way. The features were organised in a systemic network (Bliss, Monk and Ogborn, 1983).

Figure 4.1 – Systemic network’s notation

A bar in a network (see Figure 4.1) describes a response in terms of the choice of only one feature (A or B or C). A bracket provides for descriptions in terms of all its features (A, B and C).

The network constructed mainly describes the children’s responses in relation to the kind of thing the children were asked to do (i.e. the task structure), but it also allows for a description of some spontaneous types of responses. The following network represents the major categories of all types of responses:

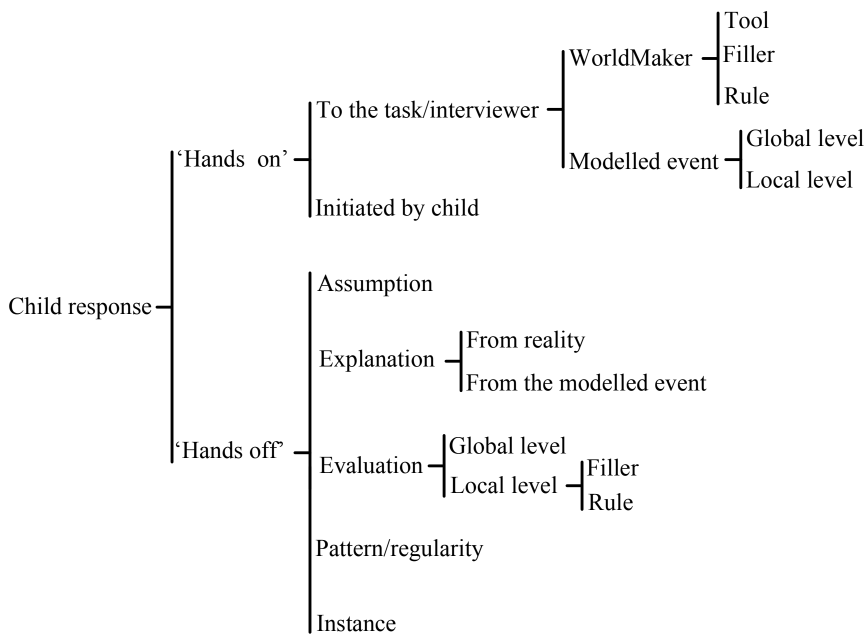


Figure 4.2 – Network for analysing the children's responses

That is, a response may be one made while working with the computer ('hands on') or while thinking about what to do or what has happened ('hands off'). Subsections 4.5.1 and 4.5.2 below consider each of the categories in the above network.

4.5.1 'Hands on' responses

The 'hands on' responses were categorised as either responses to the task/interviewer or as actions initiated by the children.

4.5.1.1 Responses to the task/interviewer

Responses to the task/interviewer were further categorised as being either to WM itself or to the modelled events.

a. WorldMaker

Responses to WM were categorised as being about the tools, the fillers or the rules.

Tools

The children easily learnt to distinguish and use the different WM tools. The most successful tools regarding their pictorial representation were the 'pencil' and the 'direction' ones. Consider the case of the 'pencil' tool. It seems likely that the 'pencil' tool was easy to interpret and learn because the tool represented by the picture of a pencil did a similar job to that of a real pencil.

It was notable that the children also insisted on using the 'pencil' tool to remove fillers, rather than using the 'block' tool for removing blocks of fillers. This may be because in ordinary life an eraser could never rub out all at once a whole set of objects. If so, perhaps they thought of the 'pencil' tool as being used rather like Tipp-Ex. Tools intended to make things easier are not necessarily accepted by children, if they are not represented by an object that functions in the same way in everyday life.

One episode concerning erasure of fillers is worth mentioning. The children had been working on removing a filler from the grid and on removing blocks of fillers. Child 2 started rubbing out some fillers one by one from the grid. Suddenly Child 1 said, "Oh, it's really like a rubber". Only when Child 2 used the mouse in a way that was similar to the way an eraser is used, did Chid 1 make the connection 'using a tool to remove a filler' = 'using an eraser'.

Thus, even though WM designers used pictorial representations for the tools, the children did not always perceive them as intended. Using Bruner's (1966) categorisation of forms of representation (*enactive*, *iconic* or *symbolic*), perhaps the following can be suggested:

i. Taking the mouse clicking as a physical activity, then the 'eraser' tool became meaningful through its enactive representation;

ii. In the same way the 'pencil' and the 'direction' tools became meaningful through their iconic representation (note that they were the most successful tools); and

iii. The representations of the other tools were less successful. Why does ■ represent the 'block' tool for example? These tools work only at the level of symbolic representation.

These points are presented in Figure 4.3.

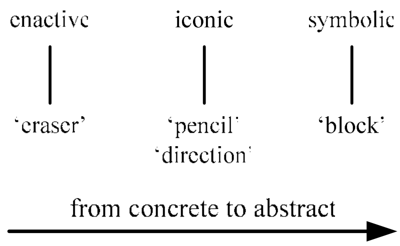


Figure 4.3 – Representation forms of WorldMaker tools

Another point of some interest is that when the model was running and the children had to do something, such as removing a filler, they almost never stopped the model first. Why?

i. Is it because they did not realise that this is simpler given the way the computer works? Or

ii. Is it because they did not imagine, as compared with everyday life, that it is possible to stop a phenomenon, change the conditions and then start again?

These remarks suggest the need for the designers to revisit some of their decisions about how tools are represented.

Fillers

In most of the research tasks, the pictures of the fillers to be used were provided. But, during the 'Aliens' task, the children had to choose a picture from a suggested list to represent a teacher. A child suggested, "Crosses, because they like to cross your work". Here they chose a symbolic but for them an evocative icon. In the same session, choosing a picture to represent an alien, another child said, "Oh, no! You have to choose from the pictures. None of them is like aliens though".

There is, here, a point worth mentioning regarding the WM version at that time: users of WM could not draw the picture of a filler that they wanted to use. They were obliged to select one picture from a suggested list that WM provided (later versions of WM do provide for drawing new pictures).

Rules

In the research tasks, the children firstly had to deal with setting the probability of a given rule ('Shopping' and 'Rabbits') and then later defining new rules ('Shark' and 'Aliens').

Usually, when the children had to define a rule they were more willing to do so by starting with the ‘Do nothing’ rule and then changing it, rather than by selecting the required type of rule from the list of rule types provided by WM.

This may be another case (remember also the case of tools), which shows that what adults think makes something easier for children, is not necessarily used by them. Or, that the categorisation of the rules according to the kind of change that they describe (change of nature of fillers, change of direction, or change of position) was not sufficiently meaningful to the children.

In the ‘Shark’ task, the children had to describe the event presented by a rule, by looking at its pictorial representation:

S	F	→		

Child 3: “The shark ate the fish and the shark died.”

F	S	→	S	S

Child 1: “The shark ate the fish and then the shark made a new one.”

The pictorial representation of a rule was not, in this case, a problem. However the children did tend to read a rule as involving more than was actually represented in it. In neither of the above rules was the action of eating actually represented. However, the children read the rule with this kind of interpretation – which in this instance was also intended.

b. Modelled event

Responses to questions about modelled events were categorised as being either at a global or local level of description.

Global level

All responses in the ‘Shopping’ and the ‘Rabbits’ tasks, where the change of the settings (i.e. probabilities) of the rules determines the behaviour of fillers, belong in this category.

In the ‘Shopping’ task, the children were dealing with the settings of the rules ‘Shopper enters’ and ‘Shopper leaves’. The settings they tried were:

Child 1: "Look how they are going to act! There is no queue! They stop when it is 100 (shopper leaves)."
Child 2: "Make it 0 (shopper enters). None will come in."
Child 1: "Go to 10 (shopper enters)."
Child 3: "Put on 10 both of them."
Child 2: "Put that (shopper leaves) on 0, and see if the whole thing is crowded. And then put on 100 to the entrance."

Even though the children seemed to have a clear idea of the way that each rule works independently from the others, they had difficulties in grasping the effect of changing the probabilities of both rules at the same time. But when (later) they were dealing with the 'Rabbits' task they had to change the setting of the rules ('Breed', 'Move', 'Die') until they obtained a population of about 30 rabbits.

Choosing as a starting point that the population of rabbits was around 30, they put 'Breed' to 30 (which is the wrong thing to do). Finding that it did not work, they started to vary the probabilities of the rules in a way that showed that they now had a clearer idea of how this works.

Why this difference between the 'Shopping' task and the 'Rabbits' task?

i. The reason may be the experience they had gained on the former task; or

ii. It might be related to the wording of the tasks. The 'Rabbits' task was stated in quantitative terms (30 rabbits) while that of the 'Shopping' one was qualitative (no queue).

Local level

In the 'Glue' task, where some of the fillers behaved a bit like glue and the children could see what shapes the glue made when it 'sets' to a solid, they were given the question: "*Can you work out where you could put the objects 'tube1' and 'tube2' to produce shapes like these?*" (see the 'Glue' task in Appendix B). The important point here was for the children to understand that the formed patterns also depended on the positions of the fillers (tubes) involved. They first put the tubes next to each other. Then one child suggested, "We should put them further apart", and they tried two cells further apart. They could have understood the effect better if they had chosen the largest possible distance apart (full screen width), but they did not tried this. However they did try varying the distance. They had difficulties (they never managed to answer the initial question) in relating the global behaviour to the local behaviour of the fillers involved.

4.5.1.2 Actions initiated by the children

On some occasions the children tried to change modelled events without being asked to, going beyond the instructions given. In nearly all cases, it was possible to see a justification.

Here are some examples:

- In the 'Bounce' task, the children had to put some balls on the grid:

  Child 1: "Put one on the wall."
  Child 3: "I don't think you can."
  All: "Aha, Yes!"

- In the 'Shopping' task:

  Child 2: "Let's try checkout there and entrance here."
  Interviewer: "To change the positions?"
  Child 2: "Yes, to put the entrance where the checkout was."

- In the 'Glue' task, the children had to clear up the grid by removing some fillers:

  Child 2: "The glue. Remove all the glue."
  Child 1: "Get rid of the wall. That piece of wall is still the source of energy I think. They are going to die!" (Child 1 was referring to the way glue representing molten rock solidifies when it touches the row of solid at the bottom of the grid.)

In the first two episodes mentioned before ('Bounce' and 'Shopping') the children tended to 'array' themselves (users) against the computer. Why? In the 'Bounce' task they were wondering about the limitations that the computer could put on their own involvement in the model, while in the 'Shopping' task they wanted to see how the computer reacts in an unexpected situation.

In the last case ('Glue' task), Child 1 had an explanation about the events taking place on the computer and wanted to verify this idea.

In the 'Shark' task, Child 3 had defined the rule 'Jump' for one shark and the children were looking at it jumping about very quickly on the grid:

All: "Aha!"
Child 3: "Lets made it slower." (Child 3 put the setting of the rule down to 50.)

Here Child 3 was intervening to make the modelled event look more realistic.

4.5.2 'Hands off' responses

Several questions in the tasks did not require use of the computer. Besides, the children often took the initiative and talked about the computer and what was represented on it, without making use of WM. In these cases, they were making assumptions or evaluations, providing explanations or instances, or looking for patterns.

4.5.2.1 Assumptions

When the children made assumptions of the type 'this will happen if I (the operator) change that', then they invoked their knowledge about the fillers or the rules.

In the 'Rabbits' task when the children were trying to fill the grid up completely with rabbits, Child 1 made the prediction: "There are going to be 300 rabbits, I know". Child 1 had noticed by looking at the 'Count' window that the grid had 300 cells, and thus was able to account for the total number of rabbits.

When working on the 'Rabbits' task, Child 2 had an idea:

> *Child 2:* "Can we put a little wall there and a little wall there?"
> *Child 1:* "You will kill all the rabbits."

In this case, Child 1 correctly assumed that putting a new object in a cell would destroy the object that was there, as WM does not allow two objects in a cell.

In the 'Shopping' task, the children were discussing the length of the queue at the exits:

> *Child 3:* "They wait here though, don't they?"
> *Child 1:* "They wait because they can't pass. Just put some more entrance." (By 'entrance' Child 1 meant the exits.)

The children knew from everyday life experience that the more exits (checkouts) you have in a supermarket the shorter the queues are at each. From this, and assuming that things happen in the same way in the computer, they inferred that having more exits would reduce the queue.

In the 'Bounce' task, the children were trying to arrange that the balls never hit one another:

> *Child 1:* "I know – that's easy. Just do balls going across. If they go like that (having parallel directions) they never hit."

In the 'Rabbits' task, the children had already worked on the settings of the rules 'Breed', 'Move' and 'Die' for rabbits, when the interviewer suggested:

> *Interviewer:* "Let's do 'Breed' 0 and 'Die' 100."
> *Child 1:* "All will just die."

In all these cases, the assumptions the children made were related to fillers or rules. It might be the case, therefore, that the children had realised that they were able to change characteristics of fillers (like the direction of their movement) and their number on the grid (either by plotting new fillers on the grid or by changing the settings of rules).

4.5.2.2 Explanations

The children's explanations came either from reality or from the modelled events.

a. From reality

Sometimes the children explained events that took place on the computer's screen by projecting from reality, that is, with an explanation that was not included in the computer model. This happened most often in three tasks: 'Bounce', 'Shopping' and 'Rabbits'.

In the 'Bounce' task, one ball was bouncing up and down and another one from side to side inside a box. Sometimes the balls hit each other, sometimes not (it depends on the size of the box in which they are moving).

> *Child 1:* "I think that they have got different speeds."

Later on, the children were asked for the boxes where the balls do not hit, to count the number of cells across and down, looking for a pattern:

> *Interviewer:* "How many are in the third box?"
> *Child 1:* "8 along and 4 down."
> *Interviewer:* "8 and 4. Here?"
> *Child 1:* "5 and 10."
> *Interviewer:* "4 and 8, 5 and 10. Can you see the relation?"
> *Child 1:* "Yes. 5x2=10, 4x2=8."

But when they had to build a box where the balls do not hit each other, they made a box (8,15) instead of a box (8,16) – their mistake was in the counting of the cells – and so the balls unexpectedly hit each other.

> *Child 1:* "They hit each other."
> *Interviewer:* "Why, what happened?"

Child 3: "The blue ball is going faster than the yellow one."
Interviewer: "But we saw before that if it is 8,4 and 5,10 they never hit. Why do they hit?"
Child 2: "It is because the distances are very big."
Child 3: "No, it is because they are even numbers."

In this task, the children explained the fact of the collision using their observation (speed, distance), and not the abstract pattern, even though they had already 'discovered' it.

In the 'Shopping' task, the children were trying to explain why sometimes there was a queue of shoppers at the checkout:

Child 2: "They have to wait for their food to be done, and then you know … to pay the bill."
Child 3: "You come here, you get your food, you come along, then you pay and …"

The children ignored the fact that the modelled event was a simplification of a real life situation, so any explanation was given as if they were looking at a real supermarket and not at the computer model of it. Thus an explanation, based on the probabilistic behaviour of a system, was not considered.

In the 'Rabbits' task, the children gave some possible reasons for the change of the number of rabbits on the grid:

Child 3: "Oh, they are less now, because they are coming and they are going away."
Child 1: "Oh, they are less. They are killing each other, no!"
Child 2: "They died."
Child 3: "Because they were old."
Child 1: "These rabbits were strong (for the ones which survived)."

When the number of rabbits was increasing, Child 1 said, "They are coming back somehow". In this case, the children did not appreciate why the number of rabbits could increase and then decrease. They were able to see a single form of behaviour – a discrete event (like the rabbits' death or their return) – and not a series of behaviours (*rabbits died*, then *rabbits returned*, then *rabbits died*, and so on).

b. From the modelled event

The children gave explanations deriving from modelled events mostly when they were dealing with the settings of the rules. Thus, in the 'Rabbits' task when Child 2 saw that the number of foxes was not increasing, it said, "Foxes cannot go up because they cannot breed (there is no 'Breed' rule for foxes)".

In the ‘Glue’ task, the children had been experimenting with two types of glue coming out from different tubes. There was runny glue, that flowed out a long way and when it became solid it created shallow sides. The other was more viscous, it did not flow as far and the sides were steep. The children were told that this process resembles the process by which volcanoes are shaped and they were asked to explain a real event (i.e. different types of volcanoes) using an explanation from the computer model (different types of glue):

> *Interviewer:* “Why do you think that some volcanoes are quite flat while others have steep sides?”
> *Child 2:* “Because they are.”
> *Child 1:* “Because lava is pushed in different ways.”
> *Interviewer:* “For this volcano, which is quite flat, what kind of tube would you use?”
> *All:* “Tube 2.”

The children were not so willing to project the model onto reality, even though they quite often did the reverse procedure (explanation of a modelled event projected from reality).

4.5.2.3 Evaluations

A modelled event was evaluated either from a global perspective or a local one. In the second case, the responses were either about the fillers or the rules.

a. Global level

Working on the ‘Shopping’ task, the children used the term *realistic*.

> *Child 1:* “It is realistic, it never moves (the queue).”
> *Interviewer:* “Why?”
> *Child 1:* “Because you have to wait ages in the real shopping queues anyway.”

For Child 1 something is realistic if it successfully imitates reality, and according to it the specific modelled event fulfilled this presupposition. The same child also said about the length of the queue, “Yes, but it depends on what country it is. If you are in Russia it isn’t realistic, there is a longer queue. In Paris it is realistic”.

Thus here the modelled event was evaluated by the criterion: Is it the same as if it took place in its natural setting?

b. Local level

Fillers

One attribute of the fillers, which really managed to attract the children's attention, was the fillers' pictorial representation – what they looked like. This was used as a reason to criticise either the fillers provided in the tasks or the fillers the children made themselves.

When Child 1 saw the picture of a rabbit on the grid it said, "They look like snails". The picture was here being regarded as giving the filler its identity.

In the 'Shopping' task, the children were discussing the length of the queue at the checkout, with the shoppers represented simply as balls.

> *Child 2:* "If somebody has more shopping, you have to wait in the queue behind for the shopping to be done. But if have less they just go quickly."
> *Child 1:* "I can't see any of them carrying shopping."
> *Child 2:* "Pretend that they are the tops of their heads and going along and you can't see their baskets."

Child 1 thought that the fillers should show the shopping carried, as one could see in real life. It is interesting that Child 2 was able to be more abstract – to suggest a way of looking at the pictures which made them acceptable.

The children paid little attention to the relative size of the pictures. For example, it did not concern them that a 'baby shark' was the same size (indeed the same picture) as its parent.

Rules

Two matters seemed to bother the children when criticising rules:

i. What are the behaviours that need to be defined by rules in order to make a model? and

ii. Which behaviours can be expressed by rules in the computer?

Regarding the first question, there were some behaviours that the children saw as not needing to be defined by rules, because they supposed that the objects of the model would have these behaviours 'by their very nature'. For instance, they wanted the alien to eat the teachers. Thus, they put the aliens on the grid away from the teachers, and defined the rule 'Alien eating teacher'. Then they expected the aliens to move towards the teachers, without giving them any rule for movement.

Clearly, the children did not always take full account of the fact that the computer is not a natural environment and that consequently, more needs to be specified than one might expect. It would be worthy if WM designers were asking themselves what behaviours of objects are likely to be considered as ‘natural assets’, not needing definition.

It was striking that it was very difficult for these children to accept that ‘unrealistic’ behaviours could ever take place in a computer model. For instance, in the ‘Shark’ task, they were given a picture of a rule that could be seen as ‘fish eating shark’. Even though they had been told that they were going to deal with some ‘strange’ rules, discussions like the following took place:

F	S	→	F	

Child 1: “The shark jumps, you see.”
Child 2: “No, the shark ate the fish.”
Child 3: “The shark jumps to an empty cell and then the fish is there.”

In the ‘Shark’ task again, the children were discussing the possibility for Fred (male shark) to give birth to babies.

Child 1: “He (Fred) can make babies.”
Children 2 and 3: “He can’t.”
Child 1: “I bet money that this computer does something like that.”

Child 1 was here arguing not about the possibility that Fred was capable of giving birth. He was arguing that ‘this’ computer could do something like that. This was the only case where a child accepted that a computer does not have to work as nature does.

4.5.2.4 Patterns/Regularities

The children talked about patterns/regularities when considering one model or different ones.

In the ‘Glue’ task, the children were observing ‘tube1’ in action when Child 2 said, “They are going to make a pattern”. But Child 1 had a different thought: “It is not a pattern. It has nothing to do with a pattern. It’s everywhere. It is just that they are going to spill everywhere”.

The children had previously worked on the ‘Rabbits’ task when they were given the ‘Shark’ one. Child 1 read the introduction to this task “*[...] The sharks move around* *the ocean, to eat fishes, to give birth to new sharks [...]*” and then said, “This is like the foxes and rabbits we did last week”.

In this case, Child 1 realised that in both tasks the pairs of the protagonists were related to each other with the same network of rules, ‘Jump’, ‘Destroys other object’, ‘Make new’, and so on. Here we have an important case of a child seeing an analogy between two models.

4.5.2.5 Instances

The children gave instances of fillers, rules and models.

In the first session, after the presentation of the fillers, the children were asked to give some examples.

> *Interviewer:* “Can you tell me something that we can treat as a background?”
> *Child 1:* “Sand.”
> *Child 2:* “Forest.”
> *Interviewer:* “Something like an object?”
> *Child 1:* “Horses.”
> *Interviewer:* “What we can put in the sand?”
> *Child 1:* “Snakes, cactus. There is not much.”

Clearly, backgrounds were thought of as representing extended areas, but objects as localised. Besides, as in the real world there are very many snakes and cactus in the sand, the computer model should ‘respect’ these attributes, representing not only the objects to be used, but also their quantity.

In the last session the children were asked to give their own instances of possible objects and backgrounds. They gave the following example: Background = space, Objects = Planet, teacher, alien. Child 1 said, “… everywhere must be space”. By contrast, in the first session the children selected objects and backgrounds very similar to those in the tasks (grass with foxes and rabbits), whilst in the last session the background filler suggested was something intangible, not having any border, the most spatial extended background that they could ever think of.

However, when they had to define a rule of their own choice, they preferred rules already known to them (like the killing one); and did not want to try others, or even to have a look at the list of rules presented to them.

When the children were asked to describe some events (models) that they would like to see on the computer, they said,

> *Child 1:* "You could see anything really."
> *Child 2:* "You could have a little street with people in their houses and then you decide where to go … and you can decide whether they will go to that shop having a certain amount of money …"
> *Child 3:* "You could click on a little box and you could see inside the house, and so you decide what you want to buy."

Taking into account the suggested situations for modelling and the fact that the children had already worked for four sessions on WM, it was clear that after this limited period of time, they had not yet fully appreciated the limitations that the specific modelling tool imposed on them. WM does not provide rules which would make following up the above ideas possible.

4.6 Understanding WorldMaker

Reviewing all these data, I came to the conclusion that one of the main findings of this small-scale study is that the determining factor that affects the utility of WM modelling facilities, as used by the children, is the nature of the tool itself. The fact that children have the chance to work on this tool, thinking simultaneously about part of the real world, is of great importance during the process of modelling. This is based on the following findings:

- The children's responses, when getting acquainted with WM, when working on pre-constructed models, or when creating their own models using it, were analogical in nature. In the former case, this means that the children learnt to use the WM tools, starting from 'real' tools which function in the same way. In the latter cases, this means that the children were invoking an analogy between the modelled event and an event from everyday life, trying to make sense of the first one.
- For these children, the analogy between the real and the artificial events was based on the fillers (objects or backgrounds) which were the protagonists of the events, and on the rules which described their behaviour. The protagonists of two analogical events should look the same (or differently only after agreement) and behave in the same way.
- If an event, which had a strong analogical relation to a real one, had to be modelled using WM then the latter would work as a prototype for the model.

Thus, in using WM in the classroom, one has to take into consideration the great importance of everyday experience and knowledge, even in the case where children are called on to play ‘God’ (create their own world).

As WM is a modelling tool which enables children to ‘imitate’ the real world, it seems to me that it is at least a powerful ‘expressive’ tool, regarding not only the expression of children’s thinking during the completion of the research tasks but also of their ‘likes’ and ‘dislikes’. What is important in this case is that children, although they are interacting with a machine, do feel free to express themselves.

The following three episodes give some evidence in favour of this last claim:

i. *Child 1:* “Put a fox in and she will kill all these disgusting little rabbits.”

ii. *Child 1:* “I can’t see any of my favourite.”
Child 3: “How do you know that’s him? They all look the same.”
Child 1: “He is still alive, he is still alive, he is still alive!”
Child 3: “How do you know that’s him?”
Child 1: “Because I know. He is still alive! Oh, he is dead! He is dead in his coffin…What a shame to die little fellow!”

iii. *Child 1:* “Yes, Fred is coming!”
Interviewer: “You prefer Fred?”
Child 1: “Yes, he is a man … And then we will see who wins. And I bet you my money that this will be sharks because they have Fred.”

4.7 Conclusions

The following questions and answers provide a broad picture of how these children managed with WM:

- Are children able to use WM?
  Yes, after spending about half an hour in a general introductory course and then dealing with specific tasks. The following questions and answers provide a more detailed picture of children’s ability to use WM as far as its main aspects are concerned:

  1. Are all of the tools recognisable?
     The tools were recognisable to this group of children in three different ways: enactively, iconically or symbolically. The most easily recognisable were the ‘pencil’ and the ‘direction’ tools while the most difficult was the ‘block’ one.

2. Do children think easily in terms of fillers (i.e. objects or backgrounds) and events?
   Yes, but not in terms of a series of actions.
3. Can children understand and define rules?
   Mostly yes. But:
      i. They had some expectations about the rules regarding the nature of fillers; and
      ii. They had some difficulties in appreciating the fact that in each WM rule only one event is described.
4. Can children work on the probability of a rule?
   Yes, but mainly following trial and error procedures.

- What might be the nature of the tasks and situations that children can use?
  As far as different modelling activities were involved, on the whole the children could cope with the questions asking for description, explanation, interpretation and exploration of a model. The hardest and the most demanding task ended up being the creation of a model. Regarding the situations to be modelled, when the children talked about any model two issues seemed to be under consideration:
     i. What a computer does; and
     ii. Whether to project reality onto the model.

  Thus, for these children any modelled situation was very much attached to its real life context.

  There are some indications, as well, that children's knowledge of the context can be important. It was noticeable that situations dealing with predator-prey relations were easier for the children to handle than situations about behaviour of materials and patterns of numbers. But the questions about the last situations demanded a more abstract level of thinking than the former. Thus, not only the familiarity of context but also the level of thinking involved has to be considered when designing WM tasks for children. The more abstract the level of thinking demanded by the task, the harder it is for children to accomplish it.

CHAPTER 5

Rationale and Design of the First Main Study

5.1 Introduction

This chapter presents the rationale and design of the first main study, which focuses on rules and their meaning for children. Initially, the main design framework (i.e. the research questions as elaborated previously in Chapter 3) is presented alongside with the criteria for constructing the research tasks. Then the focus is on the format of each task individually, showing how it addresses specific research questions.

5.2 Formulating the research questions

A modeller, when dealing with a model using a specific tool, can approach the modelling process while he/she is carrying out a number of different activities. These activities can be about the creation of a model, the description and explanation of a model's formal behaviour, the interpretation of the meaning of a model and the exploration of a model.

Modeller's modelling abilities are expressed in any of these activities and are closely related to the modelling tool used. Consequently, research looking for children's modelling abilities should focus on the nature and kind of the modelling tool used. In this study, the main idea was the concept of a WorldMaker (WM) rule and how children approach it. More explicitly, I was looking for children's ability to read, draw and create WM rules, to distinguish rules that are 'possible' and 'impossible' and to see the relation between global behaviours and local rules when they accomplish different modelling activities.

In Chapter 3, the general research questions, which form the basis of the research, were given:

- Can children understand, use and think about models in a WM form?
- Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules?

- How do children see the relation between models and the real world?

Chapter 3 also elaborated my specific research questions for this first main study. These are:

a. Can children be effectively introduced to WM by playing a board game?
b. Can children read WM rules?
c. Can children see the relation between global behaviours and WM local rules?
d. Can children replace objects in a WM rule?
e. Can children draw WM rules for a stated situation?
f. Can children create new WM rules?
g. What do children decide in terms of 'possible'/'impossible' WM rules?

Table 5.1 shows how the different modelling activities, the specific and the general research questions are related.

General research questions	Specific research questions	Modelling activities
a. Can children understand, use and think about models in a WM form?	1. Can children read WM rules? o How often do they think of the conditions? o Do they read the rules locally or globally? o According to them, do the 'before' and 'after' pictures of a rule show the same cells and do the objects in the 'before' picture interact with each other? o How do they understand the relationship between rules given as a pair? o Do they pay the same attention to different actions? o Are there variations in the difficulties of reading different WM rules? o How do they combine 'abstract' rules to make a story?	Description and explanation of a model
	2. Can children see the relation between global behaviours and WM local rules? o Can they account for the overall global effects from the nature of the rules?	Description and explanation of a model

General research questions	Specific research questions	Modelling activities
	3. Can children replace objects in a WM rule?	Exploration of a model
b. Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules?	1. Can children draw WM rules for a stated situation? o Does increasing the number and kind of action in a rule affect how well they can manage to represent it as a picture?	Creation of a model
	2. Can children create new WM rules? o What kind of actions do they tend to define on their own?	Creation of a model
c. How do children see the relation between models and the real world?	What do children decide in terms of 'possible'/'impossible' WM rules? o What reasons do they give for whether rules are 'possible' or 'impossible'? Is this related to the kind of actions considered ('realistic' or 'unrealistic')?	Interpretation of the meaning of a model

Table 5.1 – Research questions and modelling activities for the first main study

In addition, this study tried to see if children could be effectively introduced to WM by playing a board game.

5.3 Constructing the tasks

In order to address these research questions, seven research tasks were designed. One is a board game, three are computer tasks and finally three are paper tasks (the computer and the paper tasks are included in Appendix C). Two of the computer tasks were used as alternatives (half of the children did one task and the rest did the other), thus the children had to respond to six different tasks in all. The design of the research tasks was based on the following principles:

a. Suitability to introduce WM to children

Some of the research tasks should be learning tasks for WM as well, thus special care had to be taken for the tasks to be reasonable, do-able, meaningful and progressive in difficulty and complexity.

Familiarity of context, in terms of the objects involved and the actions they perform, was one of the considerations. The participants in the stories are gardeners who plant flowers, rabbits that give birth to new rabbits, foxes that kill rabbits, hunters who hunt foxes and people who get a new piece of information. A variety of WM rules, about change of nature of fillers and change of position of fillers, describe the actions of the participants. The 'Jump', 'Make new', 'Destroys other object' and 'Changes other object' rules are the most common.

Easy computer use was another matter. As some of the children had not used a computer before, the tasks ask for very simple computer manipulations, which do not have to be memorised, and a second sheet was given to the children, in which all the manipulations are presented in pictures and simple text (see Appendix A).

Progressiveness was an issue for the sequence in which the research tasks were administered to the children and for organising the questions in each task. The first tasks were a board game and a computer task. The board game was used as an introduction to the concept of a WM rule. Then, the same story was given as a computer task. The next task was also a computer one (there were two alternative tasks for the sake of exploring a wider range of models), more complex than the former in terms of the actions the participants perform and the number and complexity of questions children are asked. The next three tasks were paper ones, no computer use being involved. The first asks children to read rules and put them in a story, the second – more demanding than the first – asks for drawing of the rules that correspond to a story and the last asks children to decide about 'possible' and 'impossible' rules. This was the final one in the sequence of tasks, as it was considered that children should come to terms with the relation between models/rules and the real world, after they had gained some experience with the computer and the way that behaviours are defined. In each task, when different questions are involved, children firstly have to describe, then to modify and finally to define rules. Besides, in the computer tasks, a brief scenario is given to children to help them to make sense of the actions they will observe on the computer screen.

b. Teach/show children how WM rules work

The computer tasks have a similar structure and ask children more or less similar kinds of questions. The reason I decided to have two tasks instead of only one, is that

I wanted the children to work on more than one example of a WM model, thus having a better chance to appreciate how WM rules work. Simultaneously, I would get more of the children's responses on the same kind of questions and I would be able to explore the research issues more extensively.

c. Activities/questions should be about the nature of WM rules

A major group of questions is related to the nature of the WM rules, to the characteristics of the modelling tool used (WM) regarding the way behaviours are defined. A basic feature concerns the fact that although WM rules describe actions at a local level, they can generate global behaviours through their local behaviour. Rules and behaviours might be related in a number of possible ways to determine the nature of a task. A rule might be given and children be asked to infer the local or the global behaviour corresponding to it, or in other worlds to 'read the rule'. Being provided with an account of a local behaviour or a global one, children might be asked to identify the rule describing it, or in a different way to 'write the rule'. In the research, I wanted to find out if children read the rules locally or globally and if that is related to the kind of action involved. Thus, when children have to read a rule, nearly always the question is of the form "*What does A (A stands for an object) do?*" and children have to decide whether one object A or a whole group of them performs the action once or repeatedly. When children have to draw a rule, the description of the action is given by the task either globally or locally.

Furthermore, a different group of activities investigates a question related to children's modelling abilities, whether they are able to consider interacting rules in order to predict global effects of local rules.

Other issues are related more to the modelling tool used (WM), such as whether children pay the same attention to different actions, whether they think of conditions of actions, and whether they consider the 'before' and 'after' pictures of a rule as picturing the same cells and the fact that the objects in the 'before' part of the rule interact with each other. These issues are explored when children are asked to read rules across different tasks. Here possible differences in the difficulty of reading WM rules are investigated.

d. Questions should go beyond the specific models used

Trying to find out if children get the general idea that each rule can stand as a structure that represents different situations, two different approaches were adopted. During the board game children are asked to provide new identities for the objects pictured in a rule. Besides, often in the computer tasks as well as in the paper ones, children have to read the same kind of rule being put in a different context. For instance, children are asked to read the 'Destroys other object' rule when it represents a gardener who is taking away the flowers he does not like or a rabbit that is eating a lettuce.

e. Questions should involve different levels of working with models and rules

All the different modelling activities are included in the research: creation of a model, description and explanation of a model's formal behaviour, interpretation of the meaning of a model and exploration of a model. The modelling process is approached through the definition of rules. Thus, respectively, children have to create and draw a rule, to read and predict global effects of a rule, to decide about 'possible' and 'impossible' rules and to replace objects in a rule. During these activities children are asked to use and modify predefined rules as well as to create new rules (Maragoudaki, 1993).

f. Questions should mix work with and without computer

Although I was interested in children's understanding and use of rules, which define actions in a computer model, the children were not asked to work much on the computer when accomplishing the tasks. Amongst the six research tasks given to the children, the computer is involved in only two of them. Then, the computer is used as the medium to present a model in the *run* mode. During the last three tasks, children have to read rules and put them in a story, to draw rules representing a story and to decide about 'possible' and 'impossible' rules; and they do it on paper.

The introductory task was a non-computer board game. There were reasons for this choice, such as the limited amount of time available for the children to get acquainted with the computer and consequently avoiding a possible influence on the expression of the children's understanding of rules if the computer was used as the medium. Besides, as the main focus was on a very basic primitive feature of WM –

the way actions are defined in a model – I wanted to let the children talk about rules. For instance, in the case of reading a rule, in order to explain their decision about non-feasible rules and in order to express their predictions about the outcome of rules, the computer is of no use. If there had been more time available, the children could have worked with the computer to validate their replies. Unfortunately, that was not often possible.

5.4 The research tasks

The research tasks are presented according to the sequence in which they were introduced to the children, explaining and justifying in more detail the way they were designed. They are the following:

i. ‘Gardeners’ (board game);
ii. ‘Gardeners’ (computer task);
iii. ‘Farmers and Rabbits’ or ‘Hunters, Foxes and Rabbits’ (computer tasks);
iv. ‘Abstract’ (paper task);
v. ‘John’s party’ (paper task); and
vi. ‘Could you see these happening on the computer?’ (paper task).

For each task, a description is given first and then the following aspects are considered:

- Modelling activity involved; and
- Research questions addressed.

In the case of the ‘Gardeners’ board game, initially a justification of its introduction as the first research task is offered.

5.4.1 ‘Gardeners’ – board game

The ‘Gardeners’ board game is a simple introduction to WM. Children learn about WM before using it. An important aspect of the WM learning process is the concept of a rule. It was anticipated that by playing the board game first, thus dealing with the rules at a local level, children might be able to appreciate rather important issues for the understanding of the way a WM model evolves over time.

One is about the fundamental fact that the behaviour of the objects in a computer model – in the case of the board game, the movements of the tokens on the board – is determined by a list of rules. A second one is that each rule describes what is happening in adjoining cells, and that the picture of each rule shows a condition and an action to be taken if the condition is met. The last issue regards the way local rules interact to produce a global behaviour.

Nonetheless, a board game and a computer model differ in relation to the kind of feeling that the player (in the case of the board game) or the operator (in the case of the computer model) gets about the roles of errors, strategies, rules and fairness in a board game/computer model as shown in Table 5.2.

Board game	**Computer model**
Error	No error
Strategy	No strategy
Open rules	Closed system of rules
Fairness	Fairness is not a clear idea

Table 5.2 – Board game and computer model

In the board game the players decide which rule to apply, and the rule chosen could be the best or the worst possible choice. Players can successfully apply the rule if they move the chips according to the rule or they can make an error. They can have a strategy determined by the rules of the game and the known final target. With two players, both should follow rules, which are 'mirrored' for the game to be fair. As a result, by playing the board game, the view that the rules (kind and application) determine the outcome of a game could be corroborated to children.

Activity

The scenario given to children is about a garden in which two gardeners are growing flowers. One likes daisies (gardener D) and the other one likes roses (gardener R). The rules of the game (see Figure 5.1), determining the actions of the gardeners, are introduced to children through drawings on paper.

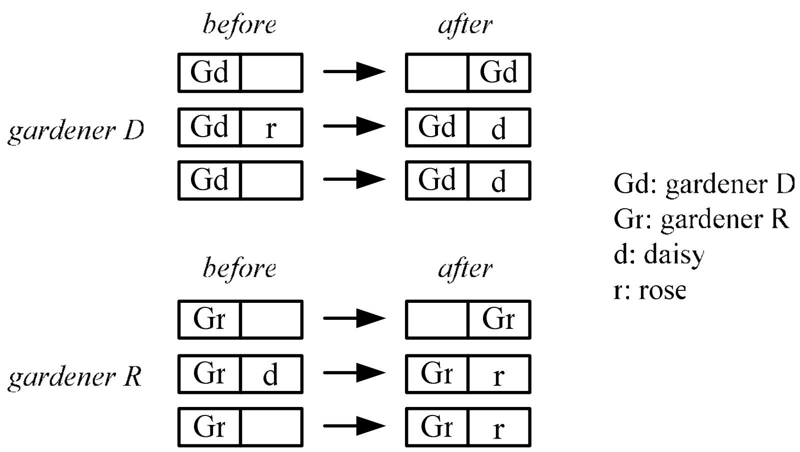


Figure 5.1 – Rules for gardeners included in the 'Gardeners' board game/computer task

Then, children are asked to reproduce them using plastic tokens standing for gardeners and flowers. Afterwards, a grid (4x4) is given to children representing a field, and they are given tokens standing for gardeners and flowers. Tokens for gardeners (one of each) are placed on the grid and children have to move them around according to the rules defining their behaviour. The winner of the game is the one who manages to have most flowers on the grid. Children are encouraged to play the game twice, each time dealing with a different gardener.

After the end of the game children are given the following questions:

i. If the gardeners are two different salesmen working in two different shops, what could we put in the places of the daises and the roses?

ii. If a daisy is a house and a rose is a block of flats, what could we use in the places of the gardeners?

iii. Do you think that a daisy could be a book, a soldier, or a cake?

iv. a) Try to define your own rule (using the chips).

b) What does this rule say?

Research questions addressed

This introductory task looks for children's ability to understand WM models and to think of situations in the 'modelling' way required by WM. Thus, children are asked to explore a model by replacing the objects in a rule (i.e. the first three questions), and to create their own model by defining their own rule (i.e. the last question).

Then, judgements can be made about how effective asking children to play a board game is for introducing them to WM.

5.4.2 'Gardeners' – computer task

The 'Gardeners' computer task was the first one the children dealt with and was their first 'encounter' with WM. It has the same context and the same rules as the board game they had played before (see Figure 5.1) in order to facilitate their understanding of WM.

Activity

The task starts by providing children with the following story: "*In a garden two gardeners are growing flowers. One is growing daisies (gardener D) and the other one is growing roses (gardener R)*".

Firstly, children are asked to load the model 'Gardeners'. When they put on the grid a gardener D and a gardener R the grid fills up with daisies and roses, until both gardeners get trapped. Children are asked to describe the model in terms of the actions taking place on the grid and to guess the rules for gardener R knowing the rules for gardener D. Then, they have to read a rule, to predict the global behaviour of the model if they apply this rule and to decide about the fairness of the model. Finally, they are given the opportunity to create their own rule.

Research questions addressed

Children have to describe and explain the WM model presented to them when they read a WM rule and while considering the relation between global behaviours and local rules. Here the general research question under investigation is whether children can understand, use and think about models in a WM form. When children are asked to create a model by creating their own WM rule, another research question is under consideration, namely whether children think in the 'modelling' way required by WM.

5.4.3 'Farmers and Rabbits'

The 'Farmers and Rabbits' computer task starts by providing children with the following scenario:

> "*Somewhere in Wales a farmer has a field where he is trying to grow lettuces. Unfortunately, there is a rabbit in his field which likes to eat the lettuces. What the farmer is trying to do is to catch the rabbit, so that he will 'save' his lettuces.*"

This task involves two different models, namely 'Farmers1' and 'Farmers2'. In both, the same objects (i.e. farmers, rabbits and lettuces) are engaged but most of the actions in which the objects are involved are different (see Figure 5.2). In both models, rabbits increase when there is empty space beside them and they do not move. In 'Farmers1', but not in 'Farmers2', another farmer will appear when a rabbit is caught and another rabbit will also appear if a lettuce gets eaten. In 'Farmers2', the farmers do not go after the rabbits. The planting of lettuces is linked to the 'Jump' rule for farmers in 'Farmers1', but not in 'Farmers2'.

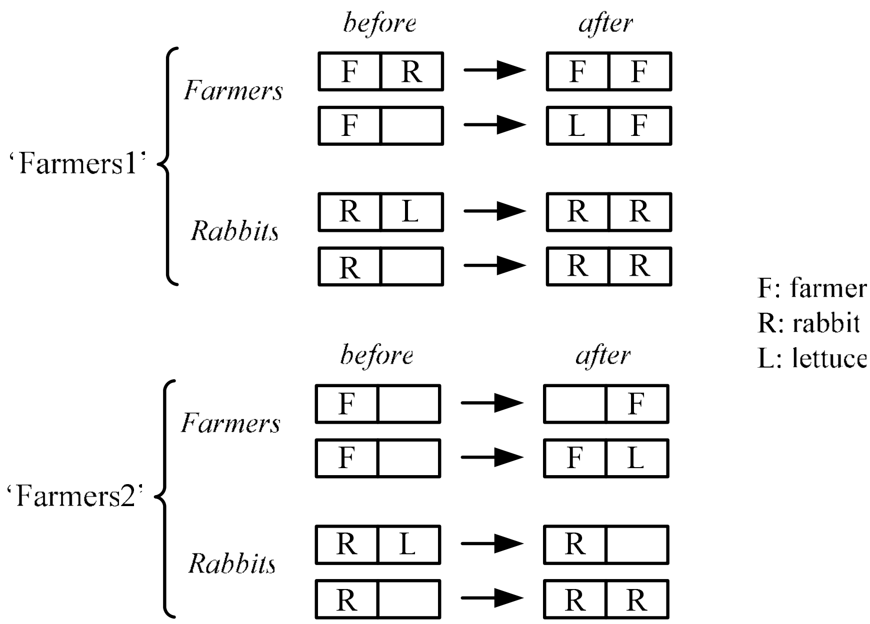


Figure 5.2 – Models included in the 'Farmers and Rabbits' task

These choices were based on the results of the preliminary study. On the one hand, the children were not expected to have problems in reading and drawing WM rules, and on the other, the children might have had difficulties in defining the global behaviour of a model by considering its local rules. Thus, the 'Farmers1' model was expected to work as an introduction to 'Farmers2'. It was anticipated that if the children focused on the actions performed by the farmers, on the rules representing them and on the global behaviour of the 'Farmers1' model, then they would be facilitated in reading the rules of 'Farmers2' and in predicting its global behaviour.

And as in both models the rabbits are reproduced, the actions of the farmers determine the final outcome of the model.

Activity

Children start by running the model 'Farmers1' and reporting the final numbers of rabbits and farmers on the grid. Then, they have to describe a specific action they have observed while the model was running, and to draw the rule describing it.

When they run the model 'Farmers2', similarly they have to report the final number of rabbits on the grid. Afterwards, an account of an action is given and they have to draw the rule corresponding to it and vice versa, to read the picture of a rule. Later, all the rules describing the actions performed in 'Farmers2' are provided and children have to give an account of them by reading the rules. At the end, they are asked to predict the outcome of the model by estimating the final numbers of farmers and rabbits.

Research questions addressed

In this task, children's understanding of WM models is under investigation when they are asked to read WM rules and to see the relation between global effects and local rules when they describe and explain a model. Children's ability to think of situations in terms of WM objects and rules is under consideration in the case of asking them to create a WM model by drawing a rule that corresponds to an action.

5.4.4 'Hunters, Foxes and Rabbits'

Alternatively to the 'Farmers and Rabbits' task, the children were given the 'Hunters, Foxes and Rabbits' computer task. The story presented in this task says that:

> "*In a field, rabbits and foxes are living. The rabbits are giving birth to new rabbits and the foxes are trying to catch the rabbits, so that they will be able to make new foxes. But when the hunters appear in the field, they are trying to trap the foxes and remove them.*"

Three different models, namely 'Fox', 'Hunters1' and 'Hunters2', are included in this task (see Figure 5.3). In 'Fox', no hunter is involved, as is the case in the other two. The objects participating in all tasks are foxes and rabbits.

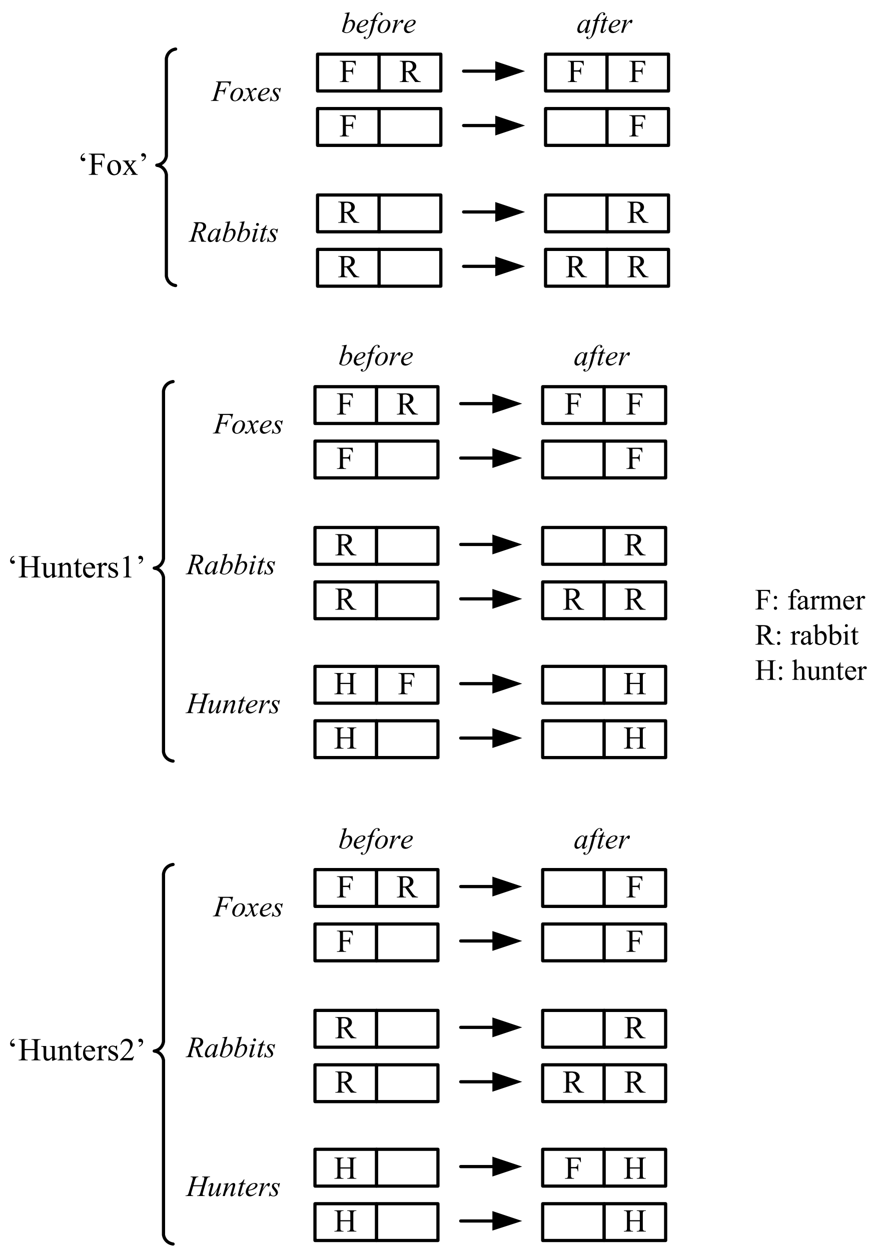


Figure 5.3 – Models included in the 'Hunters, Foxes and Rabbits' task

The 'Fox' model is really the introduction to the other two and 'Hunters1' is a preface to 'Hunters2'. Children can easily move from 'Fox' to 'Hunters1' because the only new element they have to consider is the hunters' action. In all models, the number of foxes can increase, but in a different way. In 'Fox' and 'Hunters1', a fox is reproduced when eating a rabbit, while in 'Hunters2' the hunters create new foxes and there is no rule for them to catch foxes. This 'unrealistic' situation is introduced in the last model and not before because one of the findings of the preliminary study was the children's 'attachment' to reality even in the case of a computer model. The reason for introducing this situation to the children was my intention to explore further the relation between models and the real world.

The gradual increase of complexity of rules across the different tasks was intended to help children to cope better with the questions.

Activity

Children start by loading the ‘Fox’ model and they are asked to report the final outcome of it. Then, they have to describe a specific action they have observed while the model was running and they have to draw the rule describing it. When they load ‘Hunters1’, children are asked to give an account of the actions performed by the objects involved and they have to decide if a provided group of rules is a true picture of these actions. Afterwards, the rules for ‘Hunters2’ are given and children have to read them. At the end, they are asked to predict the final number of foxes in the model.

Research questions addressed

Children’s replies when they describe and explain a model in the case of reading WM rules and looking for the relation between global behaviours and local rules, express their understanding of WM models. Furthermore, the issue of how children see the relation between models and the real world is explored when they focus on ‘unrealistic’ rules. When they create a model by drawing the rules describing it, then their ability to think of situations in terms of WM objects and rules is investigated.

5.4.5 ‘Abstract’

Children are given the pictures of six rules (see Figure 5.4). These rules were chosen so that they were either familiar to the children – they had been introduced in the previous tasks –, or they have a simple structure that allows children to approach them rather easily. Furthermore, these rules can easily be combined to make a story.

The kind of action included in the rules is about change of position of fillers (1st rule) and change of nature of fillers (2nd, 3rd and 6th rule). There is a ‘Do nothing’ rule (4th rule) as well as one rule picturing change of background (5th rule), something new for the children.

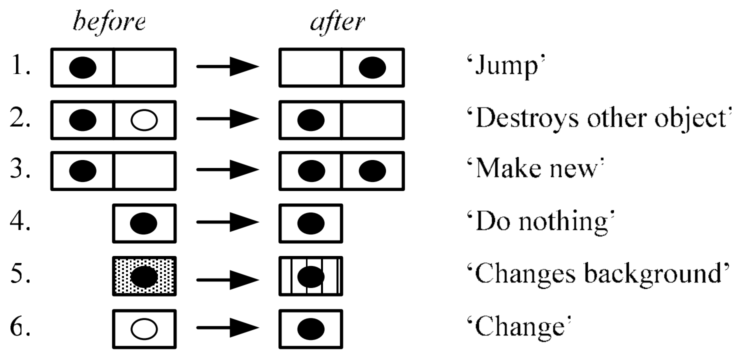


Figure 5.4 – Rules included in the 'Abstract' task

The 'Abstract' task was not a new task for the children regarding the kind of questions to which they had to respond. The innovation is that the objects involved in the rules have no identity, thus children do not have any expectations about the actions described by the rules, which may affect the way they read rules.

Activity

In this case the task itself does not provide children with any scenario. Children have to attribute identity to the objects pictured in the rules in order to read them and then to make a story using at least two rules.

Research questions addressed

When children respond to the 'Abstract' task, they exhibit their understanding of WM models. The modelling activity involved is the description and explanation of a model. When children are asked to read specific rules, the issue under investigation is whether variations in the difficulties of reading different WM rules exist. Furthermore, when they focus on WM rules to make a story, the issue explored concerns the way children combine 'abstract' rules to make a story.

5.4.6 'John's party'

Children are given the following scenario:

> "*Yesterday John had a party and he had invited a few friends. When the party started, John walked around the room looking for Peter. When he met Peter, he told him the great news, that he got a new job.*"

'John's party' is not a new task, as far as the kind of question is concerned. But there are two features that differentiate it from the other tasks. The first is about one of the rules children have to consider. The 'Changes other object' rule, that in so far has been related to a change of the nature of an object (in the 'Gardeners' board game/computer task, gardener D is changing roses to daisies), in this task is used to describe a change in one of the attributes of an object (Peter changes from ignorant to informed). Secondly, in 'John's party' the actions are not presented in a computer environment as in all the other cases where children are asked to draw a rule. It is a paper task, where children are not facilitated to focus on the kind of changes taking place in adjoining cells.

Activity

Children are asked to draw rules describing John's walk around the room and what happened to Peter when he heard the news from John.

Research questions addressed

During the 'John's party' task, children create a WM model by drawing the WM rules that correspond to a specific story and their ability to think of situations in the 'modelling' way required by WM is being explored as well as the issue of whether this ability is being affected by the kind of the action considered.

5.4.7 'Could you see these happening on the computer?'

During the last task and after spending sufficient time dealing with the concept of a WM rule doing computer and paper work, the children were asked to decide about 'possible' and 'impossible' WM rules. This task aims to investigate the way children see the relation between computer models and reality. Is the computer part of reality or does it stand as a new reality on its own?

The rules presented to children are given in the WM format with a description of the action (see Figure 5.5). The actions incorporated in the rules are of three different kinds, all describing events that children cannot see happening in real life:

i. They contradict natural expected behaviour like 'fishes eating sharks', 'people flying', 'a car changing to an elephant' and 'a man becoming invisible';
ii. The microscopic objects involved ('germs eating meat') are invisibly small, so the action is not accessible to direct observation, though the effect of many such actions could be observed; and

iii. The participants have no localised physical identity, like ‘news travelling all over the world’.

All the actions have a simple WM structure and they are chosen so as to be familiar to children. They are either about change of nature of fillers or about change of position of fillers.

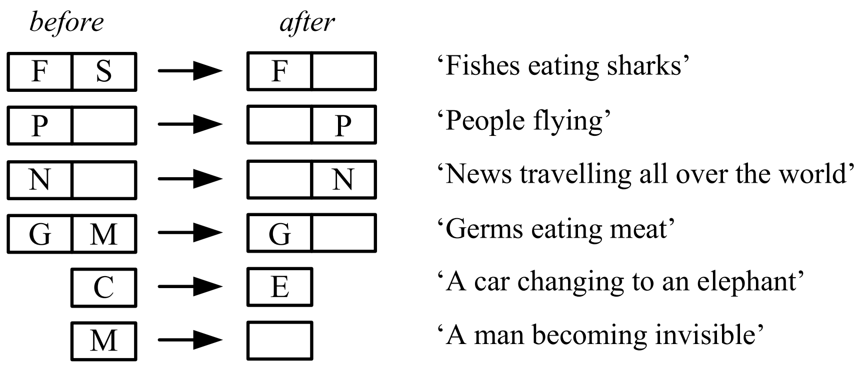


Figure 5.5 – Rules included in the ‘Could you see these happening on the computer?’ task

Activity

Children are asked to decide whether a list of actions could be observed taking place on the computer screen.

Research questions addressed

In this task, children have to interpret the meaning of a model when they are asked to distinguish ‘possible’ and ‘impossible’ WM rules, exploring the relation between models and the real world. What is also under investigation is the kind of justifications children provide for the choices they make and if that is related to the kind of actions considered (‘realistic’ or ‘unrealistic’).

5.5 Organising the study

The first main study was carried out with Year 6 pupils (aged 10-11) from two primary London inner city schools. The children were chosen by their teachers as being representative of the class average school performance and they had little experience in using the Archimedes computer. The research was carried out in three sessions as shown in Table 5.3. During the first session 32 children participated, working as 16 pairs (8 pairs from one school and 8 from the other). In the following sessions one pair could not take part thus the total number of pairs became 15. Each pair of children worked with me with one computer. There was an interval of two days between the sessions. Note also that 8 pairs carried out the 'Farmers and Rabbits' task and the remainder of the pairs (7) did the 'Hunters, Foxes and Rabbits' task.

Session	Tasks	Duration
1st	'Gardeners' – board game 'Gardeners' – computer task	60 min
2nd	'Farmers and Rabbits' 'Hunters, Foxes and Rabbits'	30 min
3rd	'Abstract' 'John's party' 'Could you see these happening on the computer?'	45 min

Table 5.3 – Presentation of the first main study's sessions

CHAPTER 6

Analysing the Results of the First Main Study

6.1 Introduction

This part of the research is about young children's understanding of and ability to use WorldMaker (WM), following an introduction to WM through a board game. The main focus of this study is on rules, an important aspect of the modelling process when using WM. What is under investigation is children's understanding and use of the idea of representing actions by WM rules. The specific research questions, which apply to the first main study, are:

a. Can children be effectively introduced to WM by playing a board game?

b. Can children read WM rules?

c. Can children see the relation between global behaviours and WM local rules?

d. Can children replace objects in a WM rule?

e. Can children draw WM rules for a stated situation?

f. Can children create WM rules?

g. What do children decide in terms of 'possible'/'impossible' WM rules?

For exploring these issues, a board game ('Gardeners') and a number of paper tasks ('Abstract', 'John's party', 'Could you see these happening on the computer?') together with computer ones ('Gardeners', 'Farmers and Rabbits', 'Hunters, Foxes and Rabbits') were designed (see section 5.4). The children's responses to these tasks are presented in this chapter.

The next section (6.2) is about the first task of this study that the children carried out, the 'Gardeners' board game. During this task, the children were learning about WM rules without yet having seen or used WM. They were asked to replace objects in a rule and make their own rules.

The children's responses to the other six research tasks are presented in section 6.3. Before or during doing these tasks, WM was introduced to and used by the children. Each task was designed to look at children's understanding of WM rules in a variety of ways. Thus each task contains a number of different types of questions. As described in Chapter 5, responses to questions of each type will be discussed together, using results across all the tasks.

An issue prior to the investigation of children's understanding of rules is whether children can notice and understand what happens on the computer's grid. For this purpose, questions in the computer tasks ask children to give a description of the computer model they are using. Confirming the results of the preliminary study (see Chapter 4), it was found that the children were nearly always able to identify the main objects participating in the actions included in a computer model and to define the kind of actions they perform as well as the way they interact with each other.

In all these tasks the children were working in pairs, and the responses are, in nearly all cases, those produced by the pair.

A summary of the findings emerging from the data presented and analysed below, which are related to the specific research questions of the first main study, is going to be presented in Chapter 9 – "Discussion and Conclusions". Also, in Chapter 9 the same data will be used to answer the main research questions and to draw the children's modelling profiles regarding their performance on the different modelling activities.

6.2 Learning about WorldMaker before using WorldMaker

The 'Gardeners' board game was the first task that the children (working in pairs) undertook. First, they played the game by moving chips on a grid, according to a set of rules written in the WM format, intended to teach them about the form of such rules. Two groups of questions followed. In the first group, the children were asked to replace the objects in this set of rules, keeping the rules' structure the same. In the second group of questions, they had to define their own rules in the WM style.

The children's performance on these questions is presented and discussed in the following two subsections (6.2.1 and 6.2.2). Here, I am trying to find out how far children can go in learning ideas essential for WM without yet using the computer. In learning WM an essential issue is the concept of a rule. In the ‘Gardeners’ board game, the focus is on two important aspects of that concept, the understanding of the nature of rules and the making of new ones. In particular, the questions address the fact that in WM the objects are arbitrary, acquiring a meaning only through rules, which describe the kind of actions in which the objects participate.

6.2.1 Replacing objects in a rule

The children were asked, in three different cases, to provide a new identity for the objects participating in the rules (see Figure 6.1) after they had played the game. The idea was to see whether they understood a rule well enough to envisage different objects obeying the same form of rule.

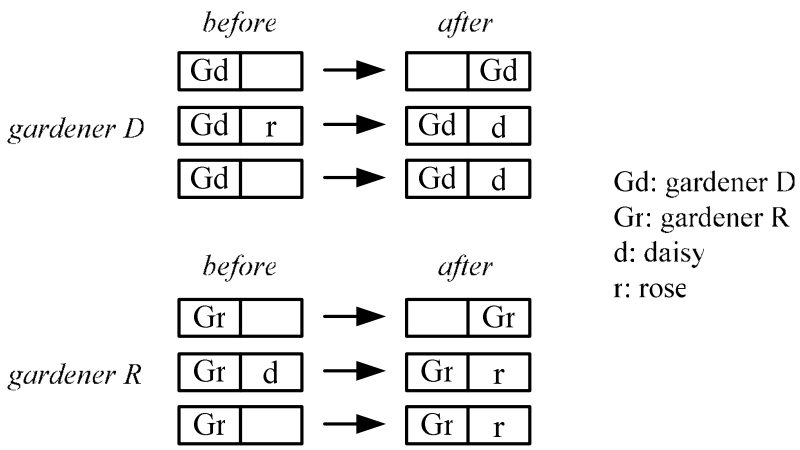


Figure 6.1 – Rules for gardeners included in the ‘Gardeners’ board game

In the first case, the two gardeners were replaced by salesmen and replacements for the flowers had to be named, then a house and a block of flats were the replacements for the flowers and the children had to substitute other objects for the gardeners. For the last question one of the flowers was replaced by a book, a soldier or a cake and the children had to find substitutes for the other flower and the gardeners.

According to the rules, there are two different kinds of objects, the ‘acting’ objects, these that change other objects – e.g. the gardeners change the flowers – and the objects that are ‘acted on’, being changed by other objects – e.g. the flowers are changed by the gardeners. The children had to identify substitutes for the ‘acted on’ objects in the first question, for the ‘acting’ objects in the second one and for both kinds of objects in the last question.

On the whole, with the exception of three pairs, the children answered all or most of these questions. The majority of the children were willing to let a chip ‘be something else’ and seemed to be able to explore a rule to a certain extent, by substituting for the objects participating. How successful and meaningful that might be appeared to be associated with the number of objects to be replaced and with the relation between the kind of action in the rules and the objects suggested as substitutes. Even though it was not easy for the children to build a whole new story analogous to ‘Gardeners’, most were able to do so for at least one case without losing sight of the abstract action/structure.

When new ‘acting’ objects – salesmen – were provided all pairs suggested some possible ‘acted on’ objects. Maybe this was because the identity of the ‘acting’ objects declared the action they could perform – to sell and buy things. Thus it was easy for the children to suggest different ‘acted on’ objects that a salesman might deal with.

When new ‘acted on’ objects – a block of flats and a house – were provided nearly all children (9/11 responses) managed to attribute an appropriate identity to the ‘acting’ objects – usually builders or estate agents.

In the case of the children being provided only with one ‘acted on’ object – a book, a cake or a soldier – the objects identified by them as possible ‘acting’ objects most often had no special function in relation to the object acted on (21/32 responses). Their actions – shown in the rules – were justified by, for example, ‘liking’ or ‘not liking’ an object.

The responses were most meaningful in the second case, that of thinking of an actor doing something to a building. Most responses were like:

> *Interviewer:* “If this is a house and this is a block of flats, what is this man doing?”
> *Child:* “He is changing the house for a flat.”
> *Interviewer:* “What could his job be?”
> *Child:* “Builder.”

This might be attributed to the fact that dealing with buildings does involve creating and destroying objects – the actions shown in the rules.

Regarding the salesmen, where ‘selling’ does not really involves creating and destroying – only replacing –, the children could not so easily provide meaningful and reasonable responses when exploring the rules. For example:

> *Child:* “You get the car and put the coin next to.”

In the case of the book, the soldier or the cake, most of the children’s responses were like “... he is knocking down the book and put a tree in its place”, which were not really meaningful. Although, it might be the case that working in the context of a new game – where the winner is the one who manages to have most of his things on the grid – the children were not concerned with whether the context of the game they suggested had a meaning. Besides, it was not an easy task for them to associate a book, a soldier or a cake with creating and destroying in a meaningful context. However, despite these difficulties it is important to notice that all the responses kept the basic structure of the rules intact. It always correctly represented the appearance or vanishing of an object, whether this seemed reasonable or not.

6.2.2 Making your own rule

At the end of the ‘Gardeners’ board game, the children were asked to define their own rules (using the chips). It was found that the children were able to pick up the idea of an action; that quite a lot of the actions they had defined were reasonable; and that they mostly treated the rules as showing single actions. They used the idea of proximity (one thing next to the other) but only some of them made the ‘before’ and ‘after’ pictures of a rule refer to the same pair of cells.

The majority of the pairs succeeded in defining their own rules (11/16). The remainder gave no response, mainly because they did not have time, since this was the last question of the task. Nearly all pairs who gave a response (10/11) provided an interpretation of the rule they had defined. In some cases this interpretation seemed rather arbitrary, but less so if understood as a variation of the board game the children had played. For instance, “Big man didn’t like the small man, and ... he takes the small man away” (compare the gardeners each removing flowers).

Half of the pairs defined more than one rule (giving 25 rules in all, 24 of which they described in some way).

The children made use of the fact that a rule depicts the accomplishment (or not) of an action rather than merely showing a state of affairs. Nearly all the rules drawn (22/25) were actually about an action, related to a change either of the nature of the objects or of their position.

In most cases (20/24), actions were presented as a 'one-off' event. That is, objects were expected to perform the action once, as opposed to this being a typical and repeated action. An example is "... he moved the chair and stood up in the same place". This is 'bad news' regarding children's modelling ability as computer modelling is most often about representing a repeated pattern of action/s.

The pairs seemed to be willing, not only to play around with the chips, but also to accept the challenge and define a variety of rules, which most often were not replicas of the ones given to them (see Figure 6.1). Out of the 25 rules defined, 16 were new, and were of 5 different kinds (see Figure 6.2). All of the new rules could stand for WM rules. As a surprise, rule 1 (i.e. the 'Jump' rule), describing actions that were very common and familiar to the children and which was one of the easiest to define, was used only three times.

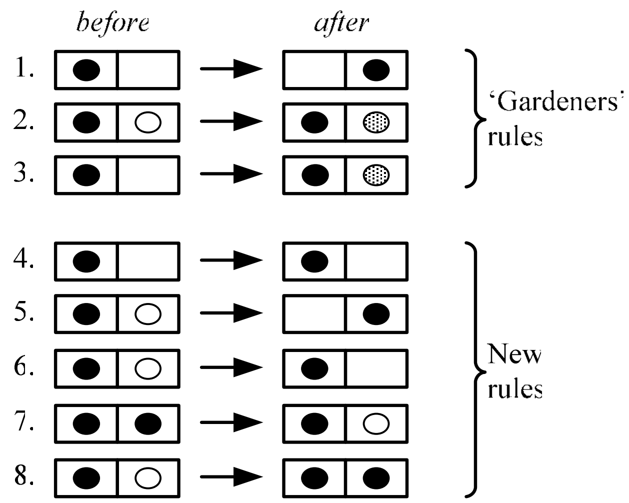


Figure 6.2 – Rules defined by the children in the 'Gardeners' board game

By contrast, the objects participating in these actions were often (15/25) those that had been involved previously in a rule, such as gardeners, flowers, books, cakes or soldiers. Thus, the children's tendency was to make the objects familiar to them perform new actions. It may be that if the same activity had been carried out in a different research setting (not at the end of the ‘Gardeners’ board game), the children would have defined different actions.

Not surprisingly, given that the children had spent only about half an hour playing with the rules, the pairs managed to give a correct account of their own rule in half of the cases (13/24). For instance, one pair defined the rule 5 (i.e. the ‘Join with other object’ rule) and said, “So, this can be a banana and this can be a gorilla. He doesn’t like it. He is eating the banana and then he moves over, he feels full and he doesn’t want to move”.

All their rules were described as representing local (not global) actions. In only a few cases (4/13) they did talk about the conditions for the actions.

On the whole, the pairs seemed to accept the convention (important in WM) that only one object can be placed in a cell. They successfully used the idea that the ‘before’ and ‘after’ pictures of a rule depict the starting point and the results of an action, respectively, as well as that the cells included in the ‘before’ and in the ‘after’ picture were next to each other. For instance, when one pair made the ‘Make new’ rule they said, “The yellow man just bought a piece of clothing from the other man”. Although the picture of the rule did not correspond to the action declared, in the ‘before’ picture the man had nothing next to him while in the ‘after’ he had a new object – the object he bought from the other man.

The children, quite often (in 7/24 responses) tended to see the ‘before’ and ‘after’ pictures of a rule as not referring to the same pair of cells, in responses to the ‘Make new’ rule like “There is a man there and he moves and he gets a gun ...”.

6.2.3 Summary of results

Without having yet seen WM and having spent only a small amount of time familiarizing themselves with WM rules, the children were able, not only to understand and modify predefined rules, but also to define their own ones, the majority of which fitted the WM format and were about ‘change of nature’ rules. Another way of saying the same thing is that the board game appears to have functioned quite well, in its intended task of introducing WM-style rules in the context of a game.

6.3 ‘Hands on’ WorldMaker

After doing the ‘Gardeners’ board game, WM was introduced and the children had to carry out a number of computer tasks together with paper ones. These tasks included questions asking them to work on single and coexisting rules and questions asking them to work on possible global effects of local rules.

6.3.1 Single rules and pairs of rules

The children were asked to work both on single rules and on pairs of rules when reading a given rule, drawing a rule to represent a given action, creating rules of their own and when deciding about ‘possible’/‘impossible’ WM rules.

6.3.1.1 Reading WorldMaker rules

The children were asked to read WM rules in three different computer tasks (‘Gardeners’, ‘Farmers and Rabbits’, ‘Hunters, Foxes and Rabbits’) and a paper task (‘Abstract’). The rules were presented either as single rules or in pairs. As a first step, the children’s reading performance is presented across the different tasks by answering the following questions:

- Can children read WM rules?
- How often do children think of the conditions?
- Do children read the rules locally (a single object performs an action – e.g. a rabbit gives birth to a baby) or globally (the overall effect of repeated performance of an action – e.g. rabbits multiply in number)?
- According to children, do the ‘before’ and ‘after’ pictures of a rule show the same cells and do the objects in the ‘before’ picture interact with each other?
- How do children understand the relationship between rules given as a pair?
- Do children pay the same attention to different actions?
- Are there variations in the difficulties of reading different WM rules?
- How do children combine ‘abstract’ rules to make a story?

‘Gardeners’

The ‘Gardeners’ computer task was carried out during the second part of the first session. The children were learning to read a WM rule and it was the first time they had met WM on the computer. The rule they had to read was similar to the others they had seen in the ‘Gardeners’ board game, the ‘Destroys other object’ rule (see Figure 6.3).

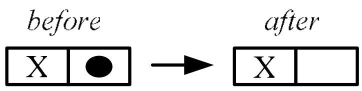


Figure 6.3 – The ‘Destroys other object’ rule included in the ‘Gardeners’ task

All pairs (16/16) read this action correctly, but only two looked at the condition under which the action took place. Only one provided a global picture of the effect of the action, “What you have to do is to get rid of as many flowers as you can”. The rest described the action as a single local event, “He took out the rose”.

‘Farmers and Rabbits’

The ‘Farmers and Rabbits’ computer task was given to eight (8) pairs in the second session. They were asked once to read a single rule (see Figure 6.4), and then two pairs of rules (see Figures 6.5 and 6.6).

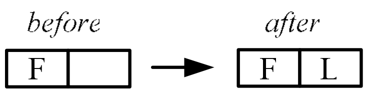


Figure 6.4 – The ‘Make new’ rule for farmers included in the ‘Farmers and Rabbits’ task

All pairs (8/8) read the above single ‘Make new’ rule correctly and locally, although a small clue was given since the condition for the action was specified by the task itself. All the responses were like “If there was empty space next to the farmer, he just planted a lettuce in front of himself”.

When dealing with the first pair of rules (see Figure 6.5), nearly all of the children read the ‘Jump’ and the ‘Make new’ rules correctly (6/8) and locally (4/6 for the first rule and 5/6 for the second one), and they tended not to mention the conditions pictured in the rules – only in 1/6 responses for each rule. In addition, there were a few cases (2/6 for each rule) where the pair of rules was treated as describing alternative actions. The non-implementation of the action for one of the rules was seen as the condition for the accomplishment of the action for the other rule, as in the response “If there is space next to the farmer and he doesn’t want lettuces, he moves”.

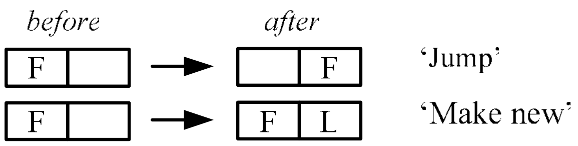


Figure 6.5 – The ‘Jump’ and ‘Make new’ rules for farmers included in the ‘Farmers and Rabbits’ task

With the second pair of rules (see Figure 6.6) the children managed equally well. All pairs described the ‘Destroys other object’ rule correctly, and nearly all did so for the ‘Make new’ rule. Only about half mentioned the conditions for either rule (4/7 for the ‘Destroys other object’ rule and 3/8 for the ‘Make new’ rule). There were a few cases (2/7 for the first rule and 1/8 for the second one) where the two rules were read as describing successive actions. Such a response was one like “If the rabbit eats all the lettuces he gets another rabbit”. In this case, the children seem to mix local and global thinking.

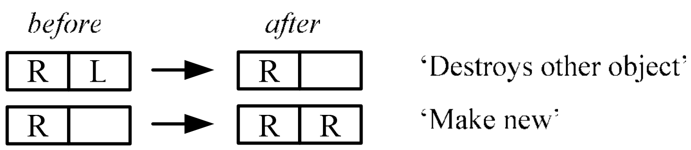


Figure 6.6 – The ‘Destroys other object’ and ‘Make new’ rules for rabbits included in the ‘Farmers and Rabbits’ task

‘Hunters, Foxes and Rabbits’

The ‘Hunters, Foxes and Rabbits’ computer task was given to the remaining seven (7) pairs in the second session. In this task, first the children had to read three single rules (see Figure 6.7) and were asked to decide if these rules accurately represented the actions in the computer model on the basis of having seen the model running. After this, three pairs of rules (see Figures 6.8, 6.9 and 6.10) were provided and the children had to read them in order to say what the participants were doing.

Regarding the first single rule in Figure 6.7 (i.e. the ‘Jump’ rule) all children read it correctly, nearly all locally (6/7) but none mentioned the conditions for the ‘jumping’ action. In the case of the ‘Make new’ rule, nearly all pairs responded (6/7) but only a few (2/6) of their responses were like “A fox is making new foxes”. Only once were the conditions mentioned and in nearly all cases (5/6), actions were described in local terms. The next single rule for the children to read was the 'Changes other object' rule. All pairs responded but only a few (2/7) gave a response such as "The hunter is moving about and killing the foxes and he makes another hunter". Conditions were not mentioned in any response and a few descriptions of the rules were global (3/7). The fact that the children had to compare the actions in the rules with the actions taking place in a computer model might be related to the way they read the rules. In the 'Make new' and the 'Changes other object' rules, the children quite often focused on the 'after' picture of the rules or the final outcome of the model in terms of the number of the objects, to point out differences or similarities (6/6 for the foxes and 4/7 for the hunters).

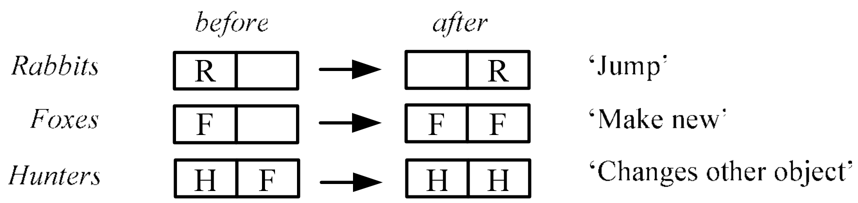


Figure 6.7 – Rules for rabbits, foxes and hunters included in the 'Hunters, Foxes and Rabbits' task

The first pair of rules (see Figure 6.8) included the 'Join with other object' rule and the 'Jump' rule. All pairs read the 'Jump' rule correctly, only one pair providing a global description of the action but only once did the children think of the conditions for the action. Only a few pairs read the 'Join with other object' rule correctly (3/7) – most considered only the 'destroying other object' action, in all cases locally. Only once were conditions discussed. Only twice were the above rules considered as describing successive actions. More common were responses like "The fox is next to the rabbit and the fox eats the rabbit. There is no rabbit next to the fox and the fox moves".

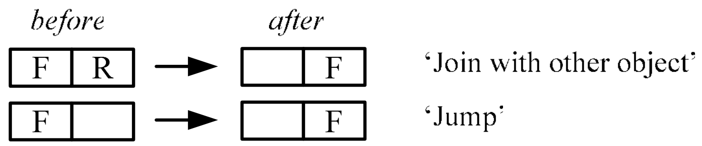


Figure 6.8 – Rules for foxes included in the 'Hunters, Foxes and Rabbits' task

The 'Jump' and the 'Make new' rules form the second pair of rules (see Figure 6.9). The children read both rules correctly and locally – only two responses were global pictures of the 'jumping' and the 'breeding' actions. No pair of children identified the conditions for the 'jumping' action. But when dealing with the 'Make new' rule, only two pairs of children (2/7) thought of a condition for the 'breeding' action – which, however, were not those actually shown in the rule. In these cases, the children considered the two rules, as describing successive actions in a response like "Rabbit is still moving, finds a mate and has a baby".

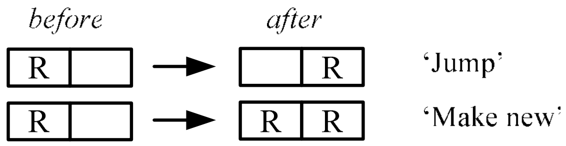


Figure 6.9 – Rules for rabbits included in the 'Hunters, Foxes and Rabbits' task

The third pair of rules (see Figure 6.10) was about hunters and foxes. All the children read the action in the 'Jump' rule correctly, nearly all locally (5/7), a few (2/7) identified the pictured conditions for the action. Only one pair described the action as taking place after the hunter moved and made a fox (note that although this is in fact the rule in the model, it is not obviously a reasonable or expected action). In the case of the 'Jump and make new' rule, nearly all pairs (6/7) read the rule locally without identifying the conditions for the action. This rule presented an exception to the otherwise uniform picture so far, in which most children read an action correctly. It showed a hunter moving and creating a fox in the space left behind. No pair saw the fox as being created by the hunter – perhaps because such an action made no sense to them. Instead, they read the rule as purely movement of hunters and foxes, for example, "The hunter is leaving the fox". This makes it important, in later analysis, to look for cases of rules on which children impose their own sense.

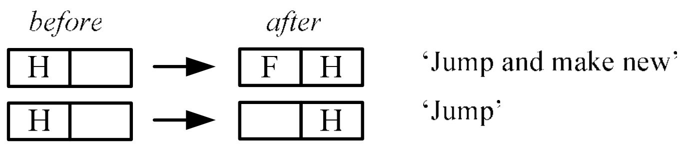


Figure 6.10 – Rules for hunters included in the 'Hunters, Foxes and Rabbits' task

'Abstract'

The 'Abstract' paper task was given in the third session. When dealing with this task, six different rules (see Figure 6.11) were given to the children to read. Firstly, they had to read each rule separately and then to construct a story using at least two of these rules.

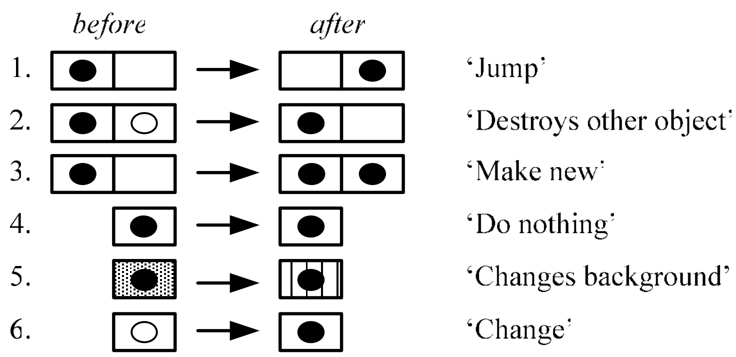


Figure 6.11 – Rules included in the 'Abstract' task

With two exceptions, all the 'abstract' rules had forms similar to those the children had met in previous tasks. The exceptions, never shown before, were the 'Changes background' and the 'Change' rules. Regarding the 'Changes background' rule the children were able to see that different backgrounds were shown in the 'before' and the 'after' pictures of the rule. Half of them attributed this difference to the movement of the object from one cell to another with a different background (7/14) or to the change of the background by itself (3/14). A response of the first kind was one like "The farmer moves to another background" and of the second kind "The background was dark and then it became light. It was dark-night and then it became morning". Only two pairs of children attributed the change of the background to the action of the object.

Another rule, which was hard for the children to handle, although it had been presented to them quite a few times and in different contexts, was the 'Make new' rule. While half of the pairs correctly interpreted the rule as the creation (breeding) of a like object – e.g. "If there is nothing in front of it, it will multiply" – the other half interpreted it as a second similar object moving to join the front one, or some other movement with the same outcome – e.g. "A hunter has a space next to him, so his friend came and helped him".

The children were more successful when they read the 'Jump' and the 'Do nothing' rules (14/14 correct responses for the first rule and 13/14 for the second one). In the case of the 'Do nothing' rule, the children often invoked the absence of any movement (9/14 responses) in responses like "The donkey didn't move", or "He has not moved, he has stayed where he was", as opposed to absence of change.

When dealing with the 'Change' and the 'Destroys other object' rules the majority were correct (9/14 for the first rule and 10/14 for the second one). When reading the first rule, the children had a stronger tendency to see an object as changing to a different object (10/13) in responses like "A daisy changes into a rose", rather than as a change to one of its properties (3/13) in responses like "The ball will be able to change colour". A few pairs (3/14) added movements (not shown in the rule) to their reading of the 'Destroys other object' rule.

Overall, the children tended to read the rules locally and not to mention the conditions for the actions included in the rules. They did focus on the conditions (4/14 responses) in the case of the 'Jump' rule. Amongst the three rules presented to the children in both ways, as 'abstract' rules and in a specific context ('Jump', 'Destroys other object' and 'Make new'), only when reading the 'Make new' 'abstract' rule was the children's performance considerably lower.

Of special interest for these 'abstract' rules is the question of whether the children gave the symbols a specific identity. It turns out that this varies according to the type of rule. Broadly, less than half the pairs added their own reading to the symbols, but more than half did so for the 'Change' (11/14) and the 'Make new' rules (9/14).

In contrast, when rules were combined to make a story, an identity was always attributed to the objects in stories like "A woman was in a flower field but she didn't like the flowers so she moved. When she moved into another field she liked it so she stayed". Objects coming from models presented to the children in the previous tasks such as farmers, foxes or gardeners, or new ones such as parents, balls or monkeys were used with the same frequency. On the whole, almost all pairs provided a story (14/15) that included at least two rules – the minimum number required by the task. In the stories, the rules were most often read correctly (19/28 rules used). The most popular rule (9/28), which was also nearly always read correctly (8/9), was the 'Destroys other object' one. The children were most unsuccessful when using the 'Changes background' rule (4/6 times used). The pair of rules used most frequently in the stories was the 'Changes background' and the 'Change' rules (5/15 stories constructed). All the children read the rules locally. Most often no conditions were mentioned and the actions included in the stories were successive and specific.

Summary of results

The children managed to read most of the rules, mostly without mentioning the conditions and locally. The easiest rule for the children to read was the 'Jump' rule and the hardest the 'Changes background' and the 'Jump and make new' rules. The 'Changes background' rule was an 'abstract' one that the children had not met before, and the 'Jump and make new' rule was about an 'unrealistic' situation. Surprisingly when 'adjacent' was an issue, the children had a stronger tendency not to reflect on the conditions, probably because all the rules in this case were about not very meaningful actions, such as an object makes another object disappear or changes it to a different kind of object. The rule that most encouraged the children to read it globally was the 'Jump' rule. This might be because it was easier for the children to visualise an object 'roaming' around the grid and repeating the 'movement' action rather than an object continually making more and more new objects. According to the children, the 'before' and 'after' pictures of a rule often show the same pair of cells and most often the children read a rule as describing an action of an object shown in the 'before' picture. In the case of pairs of rules, the children mostly read them as having no relationship. In some cases, movement appeared to be very salient. Besides, the rules that the children combined to make a story represented successive and specific actions. Furthermore, on the whole and to the degree it was investigated, the way the children read a rule did not seem to be much related to its nature ('abstract' rule or rule drawn from a specific context).

6.3.1.2 Drawing WorldMaker rules

In WM, a rule is presented as 'before' and 'after' pictures of the grid cells involved in an action, with the intention of making it easy to understand. Another way to check on how understandable the pictures of rules are (in addition to asking children to read rules in this form, as in the previous subsection) is to ask children to draw pictures of rules.

Four out of the seven tasks included questions asking the children to draw a rule representing one or more actions ('Gardeners', 'Farmers and Rabbits', 'Hunters, Foxes and Rabbits' and 'John's party'). In one task ('Gardeners'), a rule had to be drawn standing for an action the children had themselves introduced. In all the other tasks, the children had to fill in the 'before'/'after' picture of a rule for an action presented to them on the computer (‘Farmers and Rabbits’ and ‘Hunters, Foxes and Rabbits’) and/or given to them as a written account of the action (‘Farmers and Rabbits’ and ‘John’s party’). The rules the children had to draw were the ‘Jump’, the ‘Changes other object’ and the ‘Jump and make new’ rules (in the ‘Gardeners’ task they could introduce any rule). The children’s performance in drawing WM rules is discussed below for each task separately and then synthesised. The main questions to be answered are:

- Can children draw WM rules for a stated situation?
- Does increasing the number and kind of action in a rule affect how well children can manage to represent it as a picture?

‘Gardeners’

In the ‘Gardeners’ computer task the children were asked to make the picture of a rule for an action they had introduced in a previous question. All pairs that introduced an action (7/16) also provided a picture of it. In most cases (5/7 responses) the rule drawn corresponded to the action described. In nearly all of the correct responses (4/5), the rule drawn was the ‘Changes other object’ rule.

‘Farmers and Rabbits’

For the ‘Farmers and Rabbits’ computer task, the children had to draw two rules (see Figure 6.12) dealing with the same object – a farmer – after they had observed him performing these actions on the computer during the running of the model.

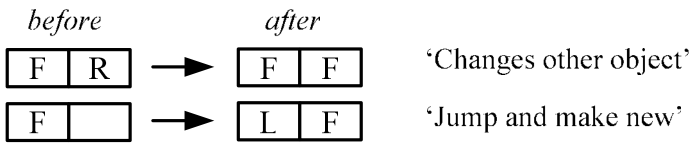


Figure 6.12 – Rules for farmers to be drawn by children

The first rule was expected to be easier to draw than the second one, as it pictured only one action and only one cell had to be filled in the ‘before’ picture, whilst the second rule included two actions (‘movement’ and ‘creation’) and the ‘after’ picture had to be defined by filling in both of the cells. Even though the children had extra help in the second case as they were also provided with a description of the rule – “... *if there was an empty space next to the farmer, he could move there and plant a* *lettuce in the place he was before*" –, they were more successful in drawing the 'Changes other object' rule than the 'Jump and make new' rule (7/7 and 4/8 correct responses, respectively). For the second rule, half of the pairs drew only one action, the 'creation', and not the 'movement'. It seems to be the case that, although the 'movement' action was particularly likely to be noticed by the children when reading a rule, they did not tend to do so when drawing a rule. The children might also be simply confused about the placement of the object after it moved.

'Hunters, Foxes and Rabbits'

The children had to draw only one rule in the 'Hunters, Foxes and Rabbits' computer task (see Figure 6.13), for an action they had just observed before running the model on the computer.

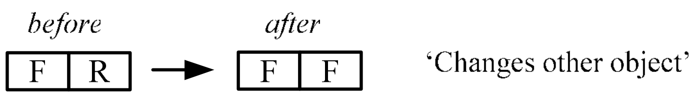


Figure 6.13 – Rule for foxes to be drawn by children

This was one more case of a 'Changes other object' rule, where the pairs had to fill in only one cell in the 'before' picture of the rule. All pairs provided a correct response (7/7).

'John's party'

In this paper task, a story was provided and the children had to draw two rules for the actions included in it. The story was about two men (John and Peter) who met at a party, where one was given a piece of information by the other. The first rule the children had to draw was the 'Jump' rule to describe "*...John's walk around the room in order to find Peter*". The second rule was a 'Changes other object' one for describing "*...what happened to Peter when he heard the news (from John)*". In both cases, when the task was given to the children, the 'before' pictures of the rules were drawn for them, and they only had to draw the 'after' pictures of the rules.

Nearly all pairs tried to accomplish this task (12/15) and nearly all of them drew the 'Jump' rule correctly (11/12). The other rule, the 'Changes other object' one, though all these 12 pairs made an attempt, was drawn correctly only by about half the pairs (5/12). However, this was the first time that the 'Changes other object' rule had to be used for a change of the state of an object – here Peter going from ‘not knowing’ to ‘knowing’ – and it would not be surprising if the children found it hard to accept this as well-represented by the change of an object. Even though two different balls were introduced in the ‘before’ picture as representing the two persons in the story – John who had a piece of information and Peter who did not – the children were not able to apply that convention to draw the ‘after’ picture of the rule. They were able to acknowledge the fact that after they met, both John and Peter had the same piece of information, but in the rule they drew, Peter was pictured the same as before.

It seems to be the case that quite a few children were not able to make sense of and use the WM ‘formalism’ in this case, according to which the only way to show that a change occurred either in the nature of an object or in one of its properties, is to represent the object using a different picture. It is likely that they thought of an object as keeping its identity regardless of the fact that one of its properties had changed.

Summary of results

Drawing simple WM rules involving one action (‘movement’ or ‘creation’ of an object) proved an easy task for the children to carry out. The children were more likely to be able to draw a rule if this rule included one action, if this action had a simple structure and if it was not about a change in the properties of the objects. However, they were less often successful when more than one action was to be represented in the same rule, or when ‘changing an object’ had to be used to represent a change in the object’s properties (about half succeeded).

6.3.1.3 Creating WorldMaker rules

At the end of the ‘Gardeners’ computer task the children were asked to create their own rule. Nearly all children (13/16) did not reply because of lack of time. Two of the three new rules created were a successful representation of the ‘changing an object’ action and one was an unsuccessful attempt at the ‘movement’ action.

6.3.1.4 ‘Possible’ and ‘impossible’ rules

In a WM model, objects are allowed to perform any action that can fit into a WM rule structure. The last task presented to the children (‘Could you see these happening on the computer?’) asked them to decide whether specific actions could be seen taking place on the computer. Each action was represented by a WM rule (see Figure 6.14).

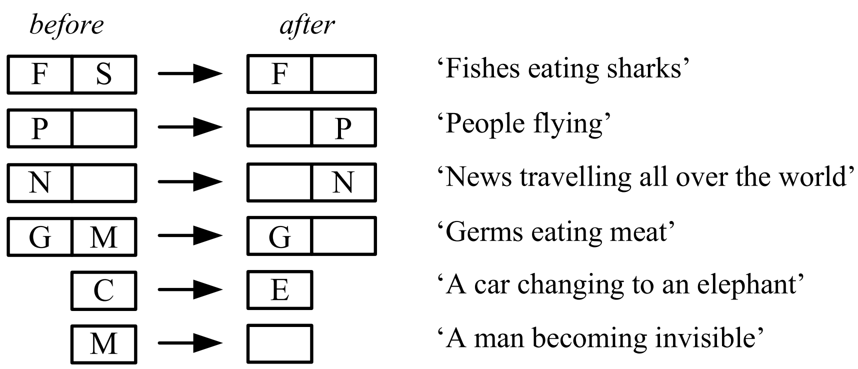


Figure 6.14 – Rules included in the 'Could you see these happening on the computer?' task

The objects involved in the actions were either concrete objects like humans and animals, or ones that have no physical identity such as 'news'. In the first case, there were actions contradicting normal expectations of what is possible, like 'fishes eating sharks', 'people flying', 'a car changing to an elephant' and 'a man becoming invisible'. There was also an action, namely 'germs eating meat', that, although it does take place in real life, cannot be observed because the objects participating in it are microorganisms. In the case of 'news', as 'news' has no physical identity it cannot be seen to perform an action like 'news travelling all over the world'.

All the actions had a simple WM structure. There were two 'Jump', two 'Destroys other object' and two 'Change' rules.

The children's responses to this task that seek to answer the general research question "How do children see the relation between models and the real world?" are presented below.

Computer models and the real world

In order to construct an overall picture of how children see the relation between a computer model and the real world across the different actions, the following questions are answered:

- What do children decide in terms of 'possible'/'impossible' WM rules?
  Nearly all pairs responded to the task (14/15) and nearly all of them decided about all the actions (6 in total). Only three pairs did not reflect on the 'news

travelling all over the world' action. Thus the total number of responses collected was 81. On the whole, the children's responses were divided roughly equally between 'possible' and 'impossible' ones (44 and 37 responses, respectively). But there were two actions – the 'news travelling all over the world' and the 'germs eating meat' actions –, for which a 'possible' response was more likely than an 'impossible' one (9/11 'possible' responses in the first case and 9/14 in the second one). Regarding 'news', it seems to be the case that the children had no problem in dealing with an action where the participant has no physical identity. Note also that, the actions of 'news' and of 'germs' were actually the only ones given that describe events that do, in fact, take place in the real world, even though they are not directly observable.

- What reasons do children give for whether rules are 'possible' or 'impossible'?
  Nearly all of the children provided a justification for the decision they made about 'possible' and 'impossible' rules (74/81 responses). There were two main categories of reasons given. One was that an action was possible or impossible because the computer could, or could not, do it. The other related not to what a computer can do, but to what can or cannot happen in reality. Thus the children giving a 'computer' response focused on the possibility of actions being represented by the computer. The children giving a 'reality' response appeared to think that an action could only be represented in the computer if it could happen in reality. In a 'possible' response, the computer was slightly more often mentioned than reality (26/44 'possible' responses). Exceptions to this were the actions 'news travelling all over the world' and 'germs eating meat'. In the first case, nearly all pairs that gave a 'possible' response did invoke reality (7/9) in responses like "News can travel because people read news, they hear news and they watch news". Regarding the 'germs eating meat' action, the children's 'possible' responses were equally divided between reality and computer (4 and 5, respectively, out of 9 'possible' responses). In a response like "Yes, because microbes come down and start eating the food" and one like "No, germs cannot eat meat in the computer. There is not such a game" the children equally favoured both. Thus, when the children were considering actions not taking place in real life, they provided a 'possible' response by mostly focusing on aspects related to the computer.

In the case of 'impossible' responses, the children mostly referred to reality (28/37 'impossible' responses), except the 'a man becoming invisible' action, where the same number of children gave reasons related to reality and to the computer (4 in each case). In this case, a response like "No, because a man can't disappear just like that. Unless he is a magician" was as common as a response like "This can be done because the next space could be empty".

- What kinds of reasons do children give for rules that they consider to be 'possible'/'impossible' for a computer?
  The children provided a variety of reasons to justify their decision about the possibility or not of an action taking place on the computer. Quite often, in responses like "Yes, because if people fly they can move one", the children considered the nature of the WM rule describing the action (12/27 justified computer responses). In other cases (6/27), the children invoked similar computer models they had 'played' in the past in responses like "It can be written on the computer because it's like the farmers' game but put in a different way". In responses like "Yes we can, because there could be lots of cars and when you press the button everything will turn into elephants", or "No, because you can't go in the whole country round the world in the computer", or "No, because in the computer it doesn't seem like flying", the children focused on the modelling process using the computer – on how the model runs or how successful the computer might be as a modelling tool (6/27). Also, when the response was like "No, because this is an educational computer and it would be teaching people that other people can fly", the children considered the ethical consequences if the action under consideration was seen on the computer (3/27).

- What kinds of reasons do children give for rules that they consider to be 'possible'/'impossible' in reality?
  When the children considered what happens in reality in order to decide if an action was 'possible'/'impossible' to take place on the computer, in a majority of cases they asserted that an action was 'impossible' simply because of the fact that it does not take place in real life (28/46). Although all the relevant actions contradicted normal expectations of what is possible, in a considerable number of their responses (18/46 'reality' responses) the children could envisage these actions as taking place in real life. According to the children, you could see

‘fishes eating sharks’ since “... there might be a fish bigger than a shark”, ‘people flying’ “like Superman”, ‘a car changing to an elephant’ in the case that “… there might be a car that got crunched up by a big machine and then made into the shape of an elephant”, ‘a man becoming invisible’ as “... there is such a thing as absence”, ‘news travelling all over the world’ so that “... people can find out what is happening”. It seems to be the case that the borderline the children drew between reality and non-reality was not easily defined and accurately predicted – what they can imagine plays a significant role.

Summary of results

When the children made a decision about the ‘possibility’ or ‘impossibility’ of a rule/action that stood as a candidate for a WM model, they considered either the tool – WM or the computer in general –, or the action itself – whether it is/is not realistic. The children were more likely to say it was possible if it was about an action that takes place in real life. If it was about an unrealistic action, but even so was thought possible, then most often they focused on different computational aspects. In nearly half these cases, they did consider the structure of WM rules.

6.3.2 Global effects of local rules

In the research tasks, the children were asked to work on a single or on a pair of local rules – when reading, drawing and creating rules and when deciding about ‘possible’/‘impossible’ WM rules – as discussed previously. However, local rules can have global effects. For example, the consequence of a rule may be that all objects of a given kind will in the end necessarily vanish or that the screen will in the end be full of (say) rabbits. To investigate this aspect of models and rules, the children were asked about the global behaviour of a computer model in three different ways. In one, they were asked to identify the local rules needed to produce a specific global behaviour (‘Gardeners’ task). Another approach was to ask them to think about the ‘fairness’ of a computer model (‘Gardeners’ task). The third way was to ask them to predict the final outcome of a computer model by considering the local rules describing it (‘Gardeners’, ‘Farmers and Rabbits’ and ‘Hunters, Foxes and Rabbits’ tasks).

The children's performance in each of these tasks will be presented next. The core of the presentation is the following questions:

- o Can children see the relation between global behaviours and WM local rules?
- o Can children account for the overall global effects from the nature of the rules?

'Gardeners'

In the 'Gardeners' computer task, a computer model was given to the children, as well as a list of rules describing the behaviour one of the participants (gardener D) and the children had to identify the rules for an analogous object (gardener R). It turned out that almost all pairs (14/16) were able to give an account of what gardener R was doing ('movement', 'making a new rose', 'changing a daisy to a rose'), probably being facilitated by the fact that in the 'Gardeners' board game they had played before, the rules for gardener R were provided.

In a different question on the same task, one of the rules was changed (gardener D simply destroys roses instead of destroying roses and creating daises) and estimations had to be made about the final outcome of the computer model in terms of number of flowers – which gardener will manage to have most of his flowers on the grid. Nearly all children responded (13/16) and nearly all of them (12/13) considered the rules in order to make a prediction. Only one pair did not provide a justification for its decision and only one pair provided a local justification. A few pairs (5/12) were able to make the right prediction and provide the right justification in responses like "Gardener R would probably win because he is digging up the flowers, he doesn't like putting a rose there instead. But gardener D is just digging up a flower and leaving a space". The most common mistake (5/12) was to focus on what one of the gardeners was doing, and not on what both of them were doing.

Another aspect of the global behaviour for the 'Gardeners' model was the concept of 'fairness'. The children were asked to decide which rules had to be changed – if any – after the 'Destroys rose' rule had been applied for gardener D, in order for the model to be 'fair'. Only a few pairs responded to this question (7/16). This very small number of responses might be attributed to the fact, that the children did not have a clear idea of what 'fairness' was. Amongst those who responded, although all of them considered what the gardeners were doing to decide whether the model was 'fair', only some pairs (3/7) suggested the right change in responses like "You don't have to plant a rose when you push the daisy out of the way".

'Farmers and Rabbits'

The rules of model 'Farmers2' (see Figure 5.2) describing what the farmers and rabbits were doing were presented to the children, and they had to predict the change of the population as far as the farmers and the rabbits were concerned, choosing from the outcomes none, one/two or more than one/two. In the case of farmers only one outcome was possible (one farmer). Conversely, in the case of rabbits more than one of the suggested outcomes were possible (two or more than two) depending on the number and kind of rules considered. But nearly all pairs focused on only one possible outcome and provided responses like "More than one because the rabbit can reproduce". Only one pair out of the six who responded considered more than one alternative outcome. Looking at rabbits they correctly said, "If the rabbit eats too many lettuces he can't make a rabbit. But if there is an empty space next to him, he can make another rabbit". In the case of farmers the same pair claimed that "If he (the farmer) plants too many lettuces he will get trapped there, so only one farmer. If he just moves along not planting too many there will be more farmers". Then, they got confused and they considered what the farmer was doing in the 'Farmers1' model (another farmer will appear when a rabbit is caught) instead of 'Farmers2' (farmers do not go after the rabbits). The confusion about which model to consider was the most common mistake when estimating the number of both, farmers and rabbits.

On the whole, in both cases the same two pairs of children did not provide a response. Out of the six responses collected, four were correct when the children decided about the number of rabbits and three were correct in the case of farmers. In addition, when looking at rules, in the case of farmers all pairs reflected on the rules as describing global actions while in the case of rabbits half of the pairs considered the rules at a local level. For rabbits, a local response might be one like "There will be more than one rabbit because when there is empty space next to him he will have another rabbit" and a global one might be like "More than one because the rabbits can reproduce".

'Hunters, Foxes and Rabbits'

In this task, rules describing what the foxes, rabbits and hunters could do were provided and the final estimated number of foxes had to be predicted supposing that the model started with two foxes (see model 'Hunters2' in Figure 5.3). According to the rules, there was only one possible outcome – at the end of the model more than two foxes could be present. All pairs responded to this question reflecting on rules at a global level (7/7). Three pairs considered two rules, but only one gave the right response "We will have more than one fox, because hunters are not killing the foxes and foxes are eating the rabbits". Some others (2/7) were probably confused about the rules of the model, providing responses related to a previous model ('Hunters1'). Such a response was one like "They will change because the hunters are killing them". None of the pairs considered the 'Jump and make new' rule for a hunter – which rather improbably said that if there was empty space next to him, he moved there and left a fox at the place he was before – to argue in favour of a possible 'more than two foxes' outcome. Again, this could be because they found the rule unreasonable.

Summary of results

On the whole, when the children were asked to focus on the global behaviour of a model, they nearly always looked at the local rules under a global perspective and they were able to see the overall effects in certain cases. The main problems they had were their tendency not to consider the interaction of rules and their avoidance of the use of rules describing implausible actions – e.g. a hunter is moving and leaving a fox behind. Regarding WM in particular, which has local rules but produces global effects – sometimes not obvious – the above findings are important for questions about how usefully such situations can be modelled with WM.

6.4 Conclusions

The first main group of conclusions concerns the overall success of the tasks and of the children's introduction to WM. To what extent did they respond to the various tasks and questions, and how well? How easily did they learn aspects of WM?

On the whole, most of the children responded to the questions of the tasks, unless there was a shortage of time. Usually the number of pairs that did not provide a response was not more than four out of the fifteen or sixteen. There was one pair that was repeatedly not willing to respond to questions; the other pairs all usually made an attempt. Regarding the children's performance across the different tasks, there was no great variation between the different pairs. Nearly always, when a response was provided, it was reasonable and comprehensible.

Learning some basic WM issues in a two or three hours session, has here been shown to be a possible task for young children. Also the board game proved to be a rather successful introduction to that process. Nevertheless, more time would be needed for more detailed familiarisation and elaborated use of WM.

The second group of conclusions concerns the children's understanding and use of WM-type rules, looked at in the various tasks from a number of different points of view:

- The children were able to 'see' the world around them in terms of actions/changes. The actions might represent a change in the nature of the participants or a change in their position.
- The children were also able to use the WM 'syntax' to represent an action in a WM-type rule. They found it meaningful to represent the action by defining the initial situation (i.e. the 'before' picture of a rule) and the final situation (i.e. the 'after' picture of a rule). They successfully used the idea of proximity, but did not always use the 'before' and 'after' pictures of a rule to refer to the same pair of cells.
- In the case of sets of rules, actions were combined to make a meaningful model. However, quite often an action was thought of as a 'one-off' event, an action that happened only once, not repeatedly or generically. The distinction is that between, for example, one person happening to catch a cold one day, and persons generally being liable to be infected.
- The children did not have problems with the use of arbitrary symbols used to represent the participants in a rule. Nevertheless, as the only way to picture a change in one of the properties of the participants is to use a different symbol, or the same symbol but changing its colour, quite often the children were not able to draw a rule for an action like 'a healthy child becomes ill'. They considered that

the identity of the child had not changed because of its illness, thus in the 'after' picture of the rule the child could not be represented differently.

- The children were able to work on the same 'abstract' WM structure when they suggested replacement objects in a WM rule and in the case of invoking similarities across different rules.

- Simple rules like the 'Jump', the 'Make new' and the 'Destroys other object' rules were easy for the children to recognise and use.

- Reading a WM rule (drawn from a specific and preferably realistic context, or an 'abstract' one) was a rather easier job than drawing one. Most often rules were read as local actions and the conditions for the actions were not considered. Most often the pairs of rules were read as being unrelated. Although making a rule was mainly explored before the children had seen or used WM, a sufficient number of children were able to define rules that fitted the WM format.

- Dealing with the global behaviour of a model was not often successful, mainly for two reasons. The first is that the children tended to focus on single rather than on interacting rules and the second is that often they avoided using or taking account of a rule if the action did not have a plausible real world interpretation.

- The issue of the real world was again involved when deciding about 'possible' and 'impossible' rules. A commonly held opinion is that children think that 'a computer can do anything' or 'if it is on the computer it must be true'. Actually, the results suggest that although there are indeed children who think 'the computer can do anything', there are more who think that 'you cannot, or you should not, make things happen on computer that cannot really happen'. Maybe they also think the computer should 'know' that such events cannot happen.

Overall, this first part of the research helped to show that WM can be accessible to quite young children (aged 10 or so), and identified some of the problems they would have in using or understanding it further.

CHAPTER 7

Rationale and Design of the Second Main Study

7.1 Introduction

This chapter presents the principles underpinning the design of the second main study. Firstly, the general research questions (see Chapter 3) and the specific ones, which apply to this study, are presented together. Then the criteria for constructing the research tasks are introduced. Each research task is then described, and finally an account is given of how the research was organised.

7.2 Formulating the research questions

In the context of a computer modelling activity, children may be asked to describe and explain the formal behaviour of a model, to interpret its meaning, to explore it or even to create a new one.

In the last case, presented with a situation, children can decide if a computer model can represent it by considering a number of different issues such as the relation between the situation and the real world, or the nature of the computer-based modelling tool used. According to the findings of the first main study, the nature of the situation ('realistic' or 'unrealistic') is very often an issue for children (see section 6.4). Afterwards, trying to model the situation using WorldMaker (WM), children have to break it into one or more elementary actions and then present each elementary action in the form of a rule.

My first main study was concerned with a problem of the second kind, namely the identification of the problems that children have in understanding and using the idea of representing actions by WM rules. In the second main study, I wanted to investigate children's ability to think of situations in terms of structures describing the elementary actions of these situations, which is a problem of the first kind. The idea was to have different models with the same underlying structure, but with very different objects and actions. At the WM level the models are identical, but not at all in terms of what they represent. Regarding this issue, I already had encouraging results from the first main study when it was found that the children were able to work on the same ‘abstract’ WM rule to represent different actions (see section 6.4). Furthermore, issues related to children’s understanding of the WM way of representing actions are explored alongside their understanding of the relation between models and reality. Thus, the following general research questions presented in Chapter 3 form the basis of this study:

- Can children understand, use and think about models in a WM form?
- Can children think about situations in the ‘modelling’ way required by WM, that is, in terms of objects and rules?
- How do children see the relation between models and the real world?

The specific research questions of the second main study are the following:

a. How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions?

b. How do children compare situations? Do they compare them in terms of actions and conditions of actions?

c. How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions?

d. How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions?

e. How do children compare participants? Do they compare them in terms of actions and conditions of actions?

f. How do children compare rules? Do they compare them in terms of actions and conditions of actions?

g. Given a set of purely ‘abstract’ rules, how do children predict whether outcomes are possible or not?

h. Is children’s tendency to look for actions and conditions of actions related to the nature of the situation considered?

i. Is children’s tendency to look for actions and conditions of actions related to the kind of question to which they respond?

j. Can children draw WM rules for a stated situation?

k. Can children understand and use rules in abstract form?

l. What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them?

m. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful?

n. Can children create a WM model using WM objects and rules?

Table 7.1 below shows how the research questions for the second main study, which correspond to specific modelling activities, are related to the general research questions that apply to my research as a whole.

General research questions	Specific research questions	Modelling activities
a. Can children understand, use and think about models in a WM form?	1. Can children understand and use rules in abstract form?	Description and explanation of a model
b. Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules?	1. How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions?	Description and explanation of a model
	2. How do children compare situations? Do they compare them in terms of actions and conditions of actions?	Description and explanation of a model
	3. How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions?	Description and explanation of a model
	4. How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions?	Description and explanation of a model

General research questions	**Specific research questions**	**Modelling activities**
	5. How do children compare participants? Do they compare them in terms of actions and conditions of actions?	Description and explanation of a model
	6. How do children compare rules? Do they compare them in terms of actions and conditions of actions?	Description and explanation of a model
	7. Given a set of purely 'abstract' rules, how do children predict whether outcomes are possible or not?	Description and explanation of a model
	8. Is children's tendency to look for actions and conditions of actions related to the kind of the situation considered?	Description and explanation of a model
	9. Is children's tendency to look for actions and conditions of actions related to the kind of question to which they respond?	Description and explanation of a model
	10. Can children draw WM rules for a stated situation?	Creation of a model
	11. Can children create a WM model using WM objects and rules?	Creation of a model
c. How do children see the relation between models and the real world?	1. What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them?	Interpretation of the meaning of a model
	2. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful?	Interpretation of the meaning of a model

Table 7.1 – Research questions and modelling activities for the second main study

7.3 Constructing the tasks

Seven research tasks ('Cats', 'Diseases', 'News', 'Disease/Rumour', 'Cat/Disease', 'ABC' and the modelling questionnaire) were designed to address the above issues (see Appendix F).

These tasks were not designed to introduce WM to children as in the first main study. They have a clear investigative character. For this reason, learning tasks should precede the research tasks during the conduct of this study. Throughout each of the first three sessions (see Table 7.2 in section 7.5), the children would firstly work on a learning task and later on a research task ('Cats', 'Diseases' and 'News'). At the end, during the fourth session they would deal with the rest of the research tasks ('Disease/Rumour', 'Cat/Disease', 'ABC' and the modelling questionnaire). Alternatively, the children could undertake all the learning tasks and afterwards focus on the research tasks. But the first three research tasks include very similar questions and it was anticipated that there was a possibility of the children getting bored if they had to do all the three tasks in one session. In addition, the children's performance in these tasks was not expected to be related to their degree of familiarity with WM. The rest of the research tasks explore different issues and they had to be administered one after the other during the last session, which did not include any learning task.

The learning tasks (see Appendix E) were designed by Boohan, Ogborn and Wright (1993), and it was decided that for each category of task – i.e. exploring a model, changing it or creating a new one – a variety of different tasks would be offered to the teachers in order to cover their needs to a greater extent. For instance, when the teachers had to teach the children how to modify the behaviour of fillers by changing the settings (i.e. probabilities) of their rules, they could choose between the 'Checkout', 'Pests' and 'Water' tasks.

The research tasks of this study were constructed according to the following principles:

a. Questions should explore children's understanding of structures

One way to approach children's understanding of structures in terms of WM actions and conditions of actions is to get them involved in the modelling process. Then, three key elements involved in modelling are under children's consideration: the situation to be represented/modelled, the model itself and the real world. The model can be presented to children in two different ways: (a) in terms of the rules describing it or (b) the rules are hidden. In this study it was decided to look for children's tendency to think of structures mainly in cases where a hint such as the picture of a WM rule is not provided. Then, children are asked to run a model in order to be able to describe it and to compare it with the situation it represents and with the real world. Furthermore, the way children see a situation – whether it is in terms of actions and conditions of actions – is also under consideration. Thus, children have to describe a situation and to compare situations with each other as well as with the real world. They have to focus on pictures of WM rules only when they have to compare rules, to compare stories being presented in terms of the rules defining them and to predict the outcome of 'abstract' rules. In these cases that represent a minority in this study, the issue under investigation is whether children being provided with pictures of rules are facilitated to look for actions and conditions of actions.

b. Stori*e*s and computer worlds instead of situations and computer models

Key notions in modelling are the situation to be represented/modelled and the computer model itself. As in the first main study, in the research tasks, a short written description of the situation to be modelled is given. In this case this is called a *story* (for examples, see pages 133-134). In each story the participants perform successive actions. The term story, which is familiar to children, implies that each story has a general theme (in the research tasks there are stories about cats, about news and about diseases) and it also avoids suggesting that the actions included in a story must be 'realistic' – a story can be a real world story or a fantasy. A computer model is introduced as a *computer world* or simply a '*world*', and this term suggests that because of its nature – it is a world on its own – a computer model has specific characteristics, such as the type of participants and the actions they perform.

c. Stories and computer worlds should be built to explore children's understanding of structures

To investigate whether children see the relations between a computer model, situation to be modelled and reality in terms of actions and conditions of actions, it is necessary first to consider what relations there can be between them. Clearly the situation to be modelled may be drawn from reality. But it may not be; the situation may be a false version of reality. For example, catching a cold may be described as caused by being out in the rain. Such a situation can still be modelled, even though it does not represent anything which happens in the real world. In addition, when dealing with the modelling process one may model a situation that cannot be distinguished as being an extract from real life or not, because the actions are attributed to 'abstract' objects that have no 'identity'; for example, they are called A and B. Furthermore, the computer model constructed may or may not correctly model the intended situation. For instance, the situation may be one in which pests eat plants, but the model may represent pests wrongly, as not affecting the plants. In the second main study, no 'abstract' story is included. Taking into account the limited time available from the schools, only 'realistic' and 'unrealistic' stories were designed for this study. This gives four combinations to be considered, shown in Figure 7.1 (a, b, c and d). The case where an 'unrealistic' story is not correctly represented by a computer world (see Figure 7.1-b) was excluded because it was likely that children would have difficulties coping with an 'unrealistic' story that simultaneously is not correctly represented by a computer world.

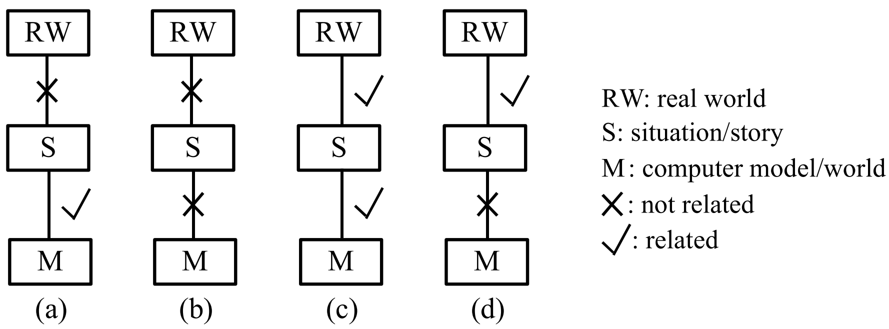


Figure 7.1 – Relations between situations, computer models and the real world

The rules selected to provide a structure for the stories and the computer worlds are only a limited number of the types of rules available in WM. They were chosen to describe simple actions and are commonly used when simple phenomena are modelled with WM (see Figure 7.2). Two of them, the 'Jump' and the 'Changes other object' rules, were amongst the rules most often used in the first main study. All the rules can be placed in a 'realistic' or an 'unrealistic' context. For instance, the 'Jump' rule can be used to describe the jumping of rabbits on a field or the movement of aliens in space.

Alongside the stories that provide a context for these rules, secondary stories are presented which differ from the main ones in terms of the rules describing them. The reason was that I wanted to see whether children, helped by the fact that in each pair of stories both are in the same context, could more easily discern similarities and differences between the two stories.

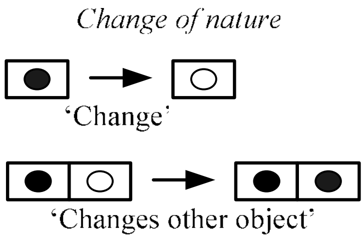


Figure 7.2 – Rules used in the research tasks of the second main study

The stories included in the research tasks fall into three groups based on their context and are the following:

- Stories about cats:

  'Cats' ('unrealistic')

  "*Try imagining that there are some creatures that are born as cats but when they meet dogs, they become dogs. Later on they change to mice.*"

  The same story is used in the 'Cats' and in the 'Cat/Disease' tasks. No secondary story is presented to children next to this one.

- Stories about diseases:

  i. 'Sick child' (main – 'realistic')

     "*On the 1st of December everybody was fine in the classroom. On the 5th one child didn't feel very well, he had got influenza, but he didn't go home, he stayed at school and at the end of the week ten children were sick. A few weeks later, the same kind of influenza was spread over again, but this time children didn't get sick, they were immune.*"

  ii. 'Ill people' (main – 'realistic')

     "*Healthy people can only catch a cold when they meet other people who already have a cold. Eventually people with colds get better.*"

     This story is described by the same kind of rules as the 'Sick child' one and is used in the 'Cat/Disease' task, while 'Sick child' is used in the 'Diseases' task.

  iii. 'Babysitter' (secondary – 'realistic')

"*In the morning, Mary had a headache and high temperature. She went to work as a babysitter looking after a three years old child. Two days later, she realised that she had got flu. She was worried about the baby, but when she called the family, they told her that the baby was fine.*"

The 'Babysitter' story is presented to children next to the 'Sick child' one in the 'Diseases' task. They differ in relation to the rules. In the 'Babysitter' story, even though one object meets another object it does not change it to one of its own (the child taken care of by Mary does not get sick).

- Stories about news:

  i. 'John's party' (main – 'realistic')

  "*Yesterday John had a party and he had invited a few friends. One of them was Peter. When John met Peter he told him the great news, that he had got a new job. Even though he told him that it was secret, Peter started to talk about it. After an hour, most people knew about it and no one talked about it any more.*"

  ii. 'Nuclear accident' (secondary – 'realistic')

  "*In the morning people didn't know anything about a serious nuclear accident which had happened. But after listening to the news at 6 p.m. most people knew about it.*"

  The 'Nuclear accident' story is presented to children next to the 'John's party' one in the 'News' task. This pair of stories has stronger differences than the pair ('Sick child', 'Babysitter'). First of all, the 'Nuclear accident' story cannot be modelled in WM as no local action is included in it – people are being informed by watching the news and not by meeting each other as in the case of the 'John's party' story. Besides, at the end of the 'Nuclear accident' story everybody is informed but nobody is bored (in the case of 'John's party' at the end of the party the people are not interested in discussing John's new job any more).

Deciding about the 'realistic' stories, the following constraints were heeded:

- o The main stories ought to be different and not have too many common features, so that children would not use the similarity of the context as a hint of the similar structure; and

- o Stories should use elements familiar to children so that they would have no difficulty in giving credence to the actions involved in them.

In the 'ABC' task, no story is given to children. Only the 'Changes other object' and the 'Change' rules (see Figure 7.2) describing a 'world' is presented and children have to predict its outcome. This is the only task where children have to work on objects, which do not have a specific real world 'identity', being called just A or B. The 'abstract' nature of the objects could help children to focus on the rules for making their predictions due to the fact that children have no expectations of what these objects might do.

The questions that accompany the above stories and 'worlds' investigate children's understanding of structures and form the following seven groups:

- <u>Group A – Description of a story or a computer world</u>

  Children are asked to describe stories or computer worlds in terms of the action of 'spreading', when they respond to the following questions that are part of the 'Diseases' and the 'News' tasks:

  1. "*How does the disease spread in the story?*" (Diseases.1);
  2. "*How does the disease spread in the computer world?*" (Diseases.2);
  3. "*How does the news spread in the computer world? In the end, have all unaware persons changed to informed?*" (News.1);
  4. "*How did the secret spread in the party? In the end, did everybody know about it?*" (News.2); and
  5. "*How did the news about the nuclear accident spread? In the end, did everybody know about it?*" (News.5).

- <u>Group B – Comparison of stories that seem similar but can have different structure</u>

  The following questions from the 'News', the 'Diseases' and the 'Disease/Rumour' tasks ask children to make comparisons between stories:

  1. "*Is what happens in the story about Mary like what happens in the story about the sick school child? How?*" (Diseases.8);

2. "*Is what happens in John's party like what happens in the nuclear accident? How?*" (News.9);
3. "*In what ways is it different?*" (News.10);
4. "*Is what happens in the story about diseases the same as what happens in the story about rumour? How?*" (Disease/Rumour.2); and
5. "*In what ways is it different?*" (Disease/Rumour.3).

- <u>Group C – Comparison of a story to a computer world</u>

  In the 'Cats', the 'Diseases' and the 'News' tasks, children are asked to compare a story to a computer world, when they respond to the following questions:

  1. "*Is what happens in the story* (i.e. 'Cats') *like what happens in the computer world? How?*" (Cats.1);
  2. "*Are they different in any way?*" (Cats.2);
  3. "*Is what happens in the computer world like the story* (i.e. 'Sick child')*? How?*" (Diseases.3);
  4. "*Is what happens in this story* (i.e. 'Babysitter') *like what happens in the computer world? How?*" (Diseases.6);
  5. "*In what ways is it different?*" (Diseases.7);
  6. "*Is what happens in John's party the same as what happens in the computer world?*" (News.4);
  7. "*Is what happens in the nuclear accident story like what happens in the computer world?*" (News.7); and
  8. "*In what ways is it different?*" (News.8).

- <u>Group D – Comparison of a story or a computer world with the real world</u>

  Children are asked to compare a story or a computer world with the real world, when they respond to the following questions from the 'Cats', the 'Diseases' and the 'News' tasks:

  1. "*Does this story* (i.e. 'Cats') *make sense?*" (Cats.3);
  2. "*Does this 'world' make sense?*" (Cats.4);

3. "*Is what happens with real diseases like what happens in the computer world?*" (Diseases.4);
4. "*Can you think of something that happens in real diseases but doesn't happen in the computer world?*" (Diseases.5);
5. "*Does this story* (i.e. 'John's party') *make sense? Why?*" (News.3); and
6. "*Does this story* (i.e. 'Nuclear accident') *make sense? Why?*" (News.6).

Children are asked to reflect on the 'making sense' attribute of a story or a computer world. They have to decide whether a story or a computer world makes sense (Cats.3 and Cats.4, respectively). Here, what is also under investigation is the issue of whether children use the relation of a situation or a computer model to the real world as a criterion to decide about the situation's/computer model's meaning.

- Group E – Comparison of participants that have similar behaviour

Children are asked to compare participants when they respond to the questions below that are part of the 'Disease/Rumour' and the 'Cat/Disease' tasks:

1. "*Is the ill person like the informed person in any way?*" (Disease/Rumour.1); and
2. "*Is the cat like the healthy person in any way*"? (Cat/Disease.3).

- Group F – Comparison of rules that have similar structure

For the 'Cat/Disease' task children have also to reply to the following two questions that ask them to compare rules:

1. "*Are your 'cats' rules similar to your 'diseases' rules? In what ways?*" (Cat/Disease.4); and
2. "*In what ways are they different?*" (Cat/Disease.5).

- Group G – Prediction of the outcome of 'abstract' rules

For the 'ABC' task, children have to predict the outcome of 'abstract' rules. The rules of a computer world are provided and children have to decide if pairs of 'before' and 'after' states of the computer world are possible. The questions are like: "*Could you see this happen in this computer world? Explain your answer.*"

(ABC.1, 2, 3, 4 and 5) or like "*Can you put these pictures in order, according to the rules? Explain your answer.*" (ABC.6). These questions also explore children's understanding of rules in abstract form.

When responding to the comparative questions of groups B, C, D, E and F, children are asked to make the comparisons in two ways: (a) by matching or (b) by matching and contrasting. A question of the first type is one like "*Is what happens in the story about Mary like what happens in the story about the sick school child? How?*". Instances of the second type are the following questions: (a) "*Is what happens in the story about diseases the same as what happens in the story about rumour? How?*" and (b) "*In what ways is it different?*". Most of the comparison questions are in pairs, one looking for similarities and the other for differences. Here children's tendency to consider different aspects of the relation between the elements compared is explored.

The questions ask children to approach a story or a computer world mainly at two different levels. At the most specific level, children have to focus on rules, on the participants or on the mechanism of specific actions. At the most general level, children have to comment on 'what happens' in a story or a computer world. In this case, children are left to decide on which aspect of the story or the computer world they want to focus on and, hopefully, they will focus on actions and conditions of actions.

d. Questions should go beyond the specific models used

The same set of rules describes all the main stories and the computer worlds used in the research tasks. Thus, excluding the questions asking for comparison of rules and prediction of the outcome of 'abstract' rules, in other cases the same research issues are explored in different contexts. For example, when comparing stories to computer worlds, children have to compare the 'Cats', the 'Sick child' and the 'John's party' stories with the corresponding computer worlds. What is under investigation is the issue of how the different nature of the context of the stories is related to children's tendency to think of the stories in terms of actions and conditions of actions. At a more general level, the fact that the main stories and the computer worlds share the same rules, allows comparisons to be made across the different groups of questions. As a result I can investigate the relation between children's ability to think in terms of actions and conditions of actions, and the kind of the question to which they respond. There are questions in which children are asked to describe a story/computer world, to compare stories, to compare a story to a computer world, to compare a story/computer world with the real world, to compare participants and rules, and to predict the outcome of 'abstract' rules. On the whole, the design of the research tasks enables me to look at the same or similar issues, several times in different ways and in varying contexts.

e. Questions should explore children's understanding of the WM way of representing actions

Questions asking children to draw the rules depicting the 'Cats' and the 'Ill people' stories are included in the 'Cat/Disease' task. Children have to draw the group of 'change of nature' rules that describe all the main stories and the computer worlds used in the tasks (see Figure 7.2). This is one of the a few cases where children have to deal with the specific way that rules are defined in WM. The reason is that I wanted to have a more complete picture of how children approach the concept of a structure, one aspect of which is the drawing of a rule. Furthermore, I could also have questions asking children to read WM rules. To save research time and having considered children's performance in reading rules during the first main study, I decided not to focus on this aspect of a structure. Children are asked to read a rule indirectly when during the 'Disease/Rumour' task they have to consider pictures of WM rules to carry out some comparisons.

f. Questions should explore children's understanding of the relation between models and the real world

Children's understanding of the relations between situations or computer models and the real world is explored in two different ways. In one case children are asked to decide whether a story or a computer world 'makes sense' (Cats.3, Cats.4, News.3 and News.6) and to write their own story that 'makes sense' to them ("*Can you write your own story that makes sense? For example, the cats could be caterpillars. What might the dogs and mice be?*" – Cats.5). Furthermore, there are questions exploring children's thinking about the reasons why a computer model works or not, and what they do think should be done about models that are not completely successful. Thus, in the modelling questionnaire four problematic modelling scenarios are presented to children, in which objects familiar to them are involved, such as healthy and ill persons, rabbits and sharks. The first two scenarios refer to computer worlds that are problematic because they do not represent the ‘realistic’ story for which they have been designed. In the third scenario, although the computer world gives the result the modeller wants the story presented is ‘unrealistic’. The fourth scenario is about a computer world which neither gives the result the modeller wants nor is it about a ‘realistic’ story. These scenarios represent three out of the four possible combinations of relations between stories, computer worlds and real life (see (a), (b) and (d) in Figure 7.1).

Dealing with these scenarios children are called upon to reflect on the way specific computer worlds function. They do not see them, but are just told that they do not work. Thus children’s responses have to be ‘in principle’. In designing the research tasks I had two alternatives; to ask children either to write down how to handle a problematic computer world or to make a choice ranging from ‘strongly agree’ to ‘strongly disagree’ from a list of statements. As my intention was to explore children’s understanding regarding specific issues of the relations between situations, computer models and the real world, the second alternative was taken. The list of statements provides reasons for a computer world to be feasible or not, and suggests what should be done about computer worlds that are not completely successful. Amongst these statements, there are some that are least acceptable from the modelling point of view. For instance, in the first scenario that is about an unsuccessful computer world, the least acceptable response is to agree with the statement “*All her rules must be wrong*”. In the second scenario – about the same computer world – the least acceptable choice is to disagree with the statement “*She should work out why people were not getting ill, before doing anything*”. The statements in these scenarios are not necessarily exclusive. In the third and fourth scenarios, the statements express two rather contradictory perspectives: one based on the meaning of a model and the other on the rule conditions. A statement of the first kind is one like “*It is more important to get rules which make sense than to get the ‘world’ to do what you want*” and of second “*A ‘world’ which does what you want is all you need*”. This was intended to find out if children consider the modelling process from a ‘semantic’ as opposed to a ‘formal’ perspective. In addition, as I was trying to find out if children are consistent in following a specific modelling perspective for a given problem and across different scenarios, the statements in the first and the second scenarios are related, as are in the third and the fourth. For instance, when the first problematic scenario is presented and a child is making the choice "*A rule is missing*", then to be consistent in the second scenario the statement "*She may need to add a rule*" has to be chosen.

g. Questions should explore children's ability to create WM models using WM objects and rules

The second part of the modelling questionnaire administered to children presents them with a global story, "*... a forest fire spreading and burning down a whole forest* ...", and they have to draw the local rules describing it. This story was chosen because although it is about the action of 'spreading' of a forest fire, it presents it from a global perspective. The same set of WM rules that describe the main stories and the computer worlds in the other research tasks of the second main study can be used to describe the spreading of a forest fire. A list of possible WM objects is offered and children have to make a choice and justify it. The list includes objects, which are appropriate to make a WM model and describe local actions, such as 'a tree', 'a tree on fire', 'a burnt tree'. Others are not well suited for a WM model. One ('fire spreading') stands for an action, and two ('whole forest' and 'burnt forest') provide a description of the grid in terms of an object. Afterwards, children have to draw the rule describing the spreading of the fire and to write down what it shows. The choices children have to make regarding the actions that describe the specific story and the objects involved in these are much related to their ability to apply the WM way of thinking, in particular their understanding of one main design principle of WM, that situations are described in terms of objects and local rules.

h. Tasks and questions should progress in difficulty and complexity

The order in which the research tasks would be presented to the children and the ordering of the questions in each of the seven research tasks were arranged so that there would be a progression in difficulty and complexity.

The first three tasks ('Cats', 'Diseases' and 'News') do not require children to focus on the specific way actions are defined in WM. 'Cats' was the first to be introduced since although it is about an 'unrealistic' situation, it has a limited number of questions and the changes included in it are about changes in the nature of the objects. Conversely, the ‘Diseases’ and the ‘News’ tasks have secondary stories as well; more questions than the ‘Cats’ task and the changes included are about changes in the properties of the objects – as it was found in the first main study that the children had difficulties in using the structure of a WM rule to represent a change in the properties of an object. The ‘Diseases’ task would precede the ‘News’ task due to the fact that it was expected to be easier for children to respond to the comparative questions regarding the main and the secondary stories in the first than in the second task. In the case where there was not enough time for giving both the ‘Diseases’ and the ‘News’ tasks, it was decided to omit the ‘News’ task.

In the first main study, it was also found that reading a WM rule was an easier task for the children than drawing one, thus the ‘Disease/Rumour’ task would be introduced before the ‘Cat/Disease’ task. The ‘ABC’ task would be presented afterwards, since I thought that an early involvement in the modelling process with such an ‘abstract’ model could create problems for the children. The modelling questionnaire was the last to be administered, in view of the fact that it investigates issues related, on the one hand, to modelling in general, such as the relation between situations, computer models and the real world, and on the other, to modelling with WM, like the creation of a WM model. The children’s experience on the learning tasks and on the former research tasks was considered essential in order to be able to handle the above issues.

As far as progression in individual research tasks is concerned, the sequence of the questions is such that descriptive questions like “*How did the news about the nuclear accident spread? In the end, did everybody know about it?*” come first in the tasks, followed by comparative questions. Firstly, this is because the descriptive questions might help children to identify the parameters of the story/computer world that they will consider when replying afterwards to the comparative questions. Besides, a descriptive question was expected to be easier than a comparative one. In the modelling questionnaire, the first two scenarios presented were more familiar to the children than the other two. They are about how people get diseases, a subject that had been introduced before in the ‘Diseases’ and the ‘Disease/Rumour’ tasks. Besides, the statements expressing different solutions for solving a modelling problem are fewer and simpler in the first two than in the last two scenarios.

i. Questions do not involve work with computer

The computer is used as the medium to present the computer worlds during the first three research tasks (‘Cats’, ‘Diseases’ and ‘News’). The only computer manipulations children have to do are very basic. Simple and written instructions, created by Boohan, Ogborn and Wright (1993), were given to the children on a separate sheet – used in the learning tasks as well (see Appendix D). All the questions included in the tasks ask for paper work. In this study, although I was interested in children’s computer modelling abilities, children’s thinking and understanding was explored without significant use of the computer. One reason is that I did not want possible difficulties in dealing with the computer interface to create an obstacle in expressing thinking and understanding. Also, during the research tasks, children are not often asked to work on pictures of WM. When they are asked to do this (to draw the rules for the ‘Cats’ and the ‘Ill people’ stories, to compare stories about diseases and about rumour, to predict the outcome of ‘abstract’ rules and to create their own computer world for a forest fire) then the use of computer might help them in anticipating their misunderstandings and difficulties. But in this case, the focus of the tasks would have changed from exploratory to teaching children firstly how to use the computer and then how to make use of WM as a modelling tool. The limited amount of time available from the schools precluded this possibility.

7.4 The research tasks

The presentation of the research tasks follows the sequence in which they would be administered to the children. They are the following:

i. ‘Cats’;

ii. ‘Diseases’;

iii. ‘News’;

iv. ‘Disease/Rumour’;

v. ‘Cat/Disease’;

vi. ‘ABC’; and

vii. The modelling questionnaire.

For each task, a short description is given first and then the following aspects are considered:

- o Modelling activity involved; and
- o Research questions addressed.

7.4.1 'Cats'

This task is about an 'unrealistic' story. The same set of WM rules describes the story and the computer world presented to children (see Figure 7.2). One of the main issues raised in this task is whether the 'unrealistic' nature of the story is related to the way children see the relation between a situation, a computer model and the real world.

Activity

Firstly, the 'Cats' story is given. Children are asked to open the computer world and watch what happens if there are only cats on the grid. Then, they have to put a few dogs on the grid and watch what happens. The first two questions ask children to compare the 'Cats' story with the computer world. Afterwards, they have to decide if the story and the computer world 'make sense' and to write a story of their own that does 'make sense'.

Research questions addressed

Children describe and explain a computer model when they consider its relation to the situation modelled. In this case children's ability to think about situations in terms of objects and rules is explored. The way they see the relation between models and the real world is under investigation during the process of interpreting the meaning of a computer model or a situation. The specific research questions are about what, for children, counts as a situation or computer model 'making sense' and whether children consider the real world when they create a situation of their own that 'makes sense'.

7.4.2 'Diseases'

In this task two 'realistic' stories are included (main and secondary). The main story ('Sick child') can be described by the 'Change' and the 'Changes other object' rules, which describe changes of an object's properties. Both rules do not apply in the secondary story ('Babysitter') in which no change is included.

Activity

Firstly, the main story about a child that gets sick when meeting another sick child is presented to children. A computer world named 'disease1' is provided and children have to watch what happens if the grid has only healthy people on it. Then they have to put a few ill persons on the grid and see what happens. The first two questions ask them to give an account of the 'spreading' action in the story and the computer world. For the third question, children have to compare the story with the computer word. The next questions ask for comparison of real diseases to the computer world. Afterwards, the secondary story about a child that does not get sick when meeting someone who is sick is presented. Children have to compare this story to the computer world and to the main story of the task.

Research questions addressed

Children's ability to think about situations in terms of objects and rules is explored in these descriptive and explanatory modelling activities. Then, children's tendency to consider actions and conditions of actions is investigated when they (a) describe the way a situation or a computer model works and (b) compare a computer model to a situation or the real world, and different situations to each other.

7.4.3 'News'

The 'News' task includes two stories, a main story ('John's party') and a secondary story ('Nuclear accident'). The main story shares the same set of rules with the other main stories ('Cats', 'Sick child' and 'Ill people'), while the secondary one cannot be described by WM rules.

Activity

The task starts by asking children to open the 'news1' computer world and see what happens (the grid has only unaware people on it). Then children are asked to put a few informed persons and watch what happens. Initially, children have to describe the 'spreading' action in the computer world and its final outcome. Then the main story is presented where an uninformed person is changed to being informed on meeting an informed person, but later changes again to being bored. Children have to describe the ‘spreading’ action in the story, to decide if the story ‘makes sense’ and finally to compare this story to the presented computer world. The secondary story is presented next and children have to describe again the mechanism for the spreading of news, to decide if this story ‘makes sense’ and to compare this story to the presented computer world. Finally, children compare the two stories in terms of similarities and differences.

Research questions addressed

During the description and explanation of a model and looking for children’s ability to think about situations in terms of objects and rules, the following issues are explored: (a) How do children describe the way a computer model or a situation works? (b) How do children compare a situation to a computer model? and (c) How do they compare situations? During the interpretation of the meaning of a model and in order to find out how children see the relation between models and the real world, children are asked to decide whether the given situations ‘make sense’ to them.

7.4.4 ‘Disease/Rumour’

The ‘diseases’ and the ‘rumour’ stories are presented to children in terms of the rules (i.e. ‘Change’ and ‘Changes other object’) describing them. These rules also describe all the main stories and the computer worlds included in the previous research tasks.

Activity

The first question asks children to compare one of the participants in the ‘diseases’ story with one of the participants in the ‘rumour’ story. Then children have to compare the corresponding stories being described by the rules.

Research questions addressed

During the description and explanation of a model, children’s ability to think of situations in terms of objects and rules is explored by asking them to compare participants in two situations and to describe similarities and differences between situations.

7.4.5 'Cat/Disease'

This task asks children to work on pictures of WM rules. It presents two stories ('Cats' and 'Ill people') familiar to children from the 'Cats' and the 'Diseases' tasks. Both stories share the same set of WM rules.

Activity

Children firstly have to draw the rules describing the two stories. Then they have to compare two participants in the stories and the rules describing the stories.

Research questions addressed

Children's ability to think about situations in terms of objects and rules is explored when considering how children compare rules and participants as well as when they have to draw the rules describing two situations. In the first case the modelling activity under consideration is the description and explanation of a model. When drawing of rules is involved, children create WM models.

7.4.6 'ABC'

This task presents the rules of a computer world about A, B and C (objects with no specific 'identity'). These rules are of the same kind as those used in the 'Disease/Rumour' task. Five pairs of possible 'before' and 'after' states of the computer world are provided and children have to state which pair is the outcome of the 'abstract' rules (only one is possible). Due to a designing mistake, only two 'change of nature' rules were included in the computer model. Then, all the five pairs of possible states of the model would be impossible, unless the children assumed that the objects were able to move, although no rule was defined for this action. In addition, three states of the computer world are also presented to children and they have to put them in sequence.

Activity

Children are asked to predict the outcome of 'abstract' rules in six different cases.

Research questions addressed

Looking for children's ability to think about situations in terms of objects and rules, the focus is on the way children predict whether outcomes of 'abstract' rules are possible or not. Furthermore, when the issue under consideration is whether children are able to understand and use rules in abstract form, the general research question under investigation is about children's understanding, use and thinking about models in a WM form. In both cases, the modelling activity carried out regards the description and explanation of a model.

7.4.7 The modelling questionnaire

The modelling questionnaire would be the final research task given to the children. It has two different parts (see Appendix F).

Activity

In each of the first four problematic modelling scenarios, children have to declare their agreement or disagreement with each of the possible solutions suggested. In the second part of the questionnaire about how to make a computer model, firstly children have to choose the objects they want to use from a suggested list ('a tree', 'whole forest', 'a tree on fire', 'fire spreading', 'a burnt tree' and 'burnt forest') and to explain their decision. Then they are asked to draw one rule describing the computer model, explaining what the rule shows. Finally, if they have time, they can suggest some other objects and rules they might use.

Research questions addressed

The first part of the questionnaire, about the interpretation of the meaning of a computer model, looks for the way children see the relation between models and the real world. The specific research question investigated is: What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful? The second part, about the creation of a WM model, tries to investigate children's ability to create WM models using WM objects and rules.

7.5 Organising the study

The second main study was carried out with 124 children from three schools (A, B and C). Schools B and C participated with nearly the same number of children while school A with nearly half the number of the others. The children from schools A and C were Year 8 (aged 12-13) and were part of the Information Technology Group, while the children from school B were Year 9 (aged 13-14) and were part of the Science Group. All the children had previous experience in using the Archimedes computer in the classroom.

My initial plan was to work with children from the last years of primary education because I was interested in exploring the modelling abilities of the youngest likely possessors of such skills. In addition, I had clear indications from the first main study that children of this age could handle WM. But, a practical problem occurred and my initial plan had to be changed. As I wanted a large number of children to participate in this study, I had to administer the research tasks not to individual children but to whole classes. That turned out to be impossible for the primary schools I gained access to because they had only one or at maximum two Archimedes computers. Thus I decided to turn my attention to children from the first years of secondary education where a larger number of computers were available at schools.

In this study, WM was used as a tool to familiarise children with the process of modelling and the concept of structures. Thus they had to spend a substantial amount of time with the computer. I judged that four sessions (of about an hour each) might be enough and would be the most that could be obtained from the schools (see Table 7.2).

After going to schools and meeting the teachers a few changes had to be made to the plan. Firstly, it became apparent that the suggested sequence of the learning and research tasks would have be adjusted for each class. Each class was used to a different degree of intensive work and each teacher wanted to use the learning tasks in a way that would serve her/his own teaching objectives. The necessary alterations were made in so far as they would not be likely to have a significant effect on the children's performance in the research tasks and on the data collected. Appendix G shows how the learning and the research tasks were actually used in each class.

It then became clear that the teacher of school C was not willing to administer the learning and the research tasks to her/his pupils. I decided to play her/his role, after considering the fact that according to the plan there was really no instructor interference when the children were responding to the research tasks' questions, bearing in mind that this was a substantial group of children that should not be missed.

In the other two schools, I was present when the learning and the research tasks were given but the teachers were responsible for organising the activities. In school B, the ‘News’ task was omitted, because time with the children was limited.

Session	Learning tasks	Research tasks	Duration
1st	• ‘Bounce’; or • ‘Pond life’; or • ‘Glue’ (Children are given fillers which have already been created)	• ‘Cats’	60 min
2nd	• ‘Checkout’; or • ‘Pests’; or • ‘Water’ (Children modify the behaviour of fillers by changing the probabilities of their rules)	• ‘Diseases’; or • ‘News’	60 min
3rd	• ‘Cars’; or • ‘Rabbits’; or • ‘Coastline’ (Children create entirely new types of fillers by building new sets of rules)	• ‘Diseases’; or • ‘News’	60 min
4th		• ‘Disease/Rumour’; • ‘Cat/Disease’; • ‘ABC’; and • The modelling questionnaire	60 min

Table 7.2 – Presentation of the second main study’s sessions as originally designed

CHAPTER 8

Analysing the Results of the Second Main Study

8.1 Introduction

The purpose of the second main study was mainly to investigate children's ability to think of situations in terms of structures as well as their understanding about the relationship between models and reality. Regarding structures, the children were asked to describe and compare stories (situations), computer worlds (computer models), objects participating in actions, rules, and to predict the outcome of 'abstract' rules. The actions included in these situations, computer models and rules as well as those performed by specific objects shared the same structure; the same set of WorldMaker (WM) rules described all. The intention was to find out whether children are able to use a WM rule as a tool to compare elements which, although looked different, the same underlying structure could explain all the actions involved. Besides, the children's understanding of structures was also explored when they were asked to draw the WM rules describing a story. Furthermore, the children were asked to focus on the relationship between models and reality when they had to reflect on the 'making sense' attribute of a situation or a computer model and to decide about successful computer models. Thus, in this study, the specific research questions under investigation are the following:

a. How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions?

b. How do children compare situations? Do they compare them in terms of actions and conditions of actions?

c. How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions?

d. How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions?

e. How do children compare participants? Do they compare them in terms of actions and conditions of actions?

f. How do children compare rules? Do they compare them in terms of actions and conditions of actions?

g. Given a set of purely 'abstract' rules, how do children predict whether outcomes are possible or not?

h. Is children's tendency to look for actions and conditions of actions related to the nature of the situation considered?

i. Is children's tendency to look for actions and conditions of actions related to the kind of question to which they respond?

j. Can children draw WM rules for a stated situation?

k. Can children understand and use rules in abstract form?

l. What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them?

m. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful?

n. Can children create a WM model using WM objects and rules?

A number of research tasks were designed (see Chapter 7) which were administered to the children alongside some learning tasks (see Appendix E) introducing WM.

This chapter is structured as follows. Firstly an overview of the analysis of the children's responses about structure and the overall results are provided. Afterwards, these are considered in terms of their correctness and generality, followed by detailed profiles of responses for each group of questions (see section 8.2). Then, the children's performance in writing rules (see section 8.3) and stories (see section 8.4), and their replies to a modelling questionnaire (see section 8.5) are discussed. Finally, some concluding remarks are made (see section 8.6).

A short account of the findings emerging from the data presented and analysed here, which are related to the specific research questions of the second main study, is given in Chapter 9 – "Discussion and Conclusions". Furthermore, two more issues will be explored: the way and the extent to which these data throw some light on the general research questions as well as sketching children's modelling abilities when carrying out different modelling activities.

8.2 Looking for structures

Looking for evidence about children's ideas of structures, the research tasks were designed to look at structures in a variety of ways. The tasks had to be set in a variety of contexts with a variety of questions. Thus, one task was designed to be about an 'unrealistic' situation (cats meet dogs and change to dogs), others about 'realistic' ones (healthy people meet ill ones and become ill and uninformed people meet informed ones and become informed) and in one task objects with no real world 'identity' (object A meets object B and changes to B) are involved. The questions included in the tasks sample a range of issues and are spread throughout the different tasks. They fall into seven groups, in connection with the issues about structure that they explore:

A. Questions asking children to describe a story or a computer world;

B. To compare stories that seem similar but can have different structure;

C. To compare a story to a computer world;

D. To compare a story or a computer world with the real world;

E. To compare participants that have similar behaviour;

F. To compare rules that have similar structure; and

G. To predict the outcome of 'abstract' rules.

Although the questions included in the tasks form seven different groups, it cannot be taken for granted that all questions in a group are comparable. Thus, the questions will be looked at individually in order to consider whether it is appropriate to 'average' over them as a group, or whether it is better to explain the results individually. In this way, we will look for possible context dependence.

In order to be able to compare the responses, it is necessary to identify features of them which can be compared. These features have to be concerned with children's understanding of structures of models and different ways of understanding a model.

Thus we will be able to look for whether children can think in terms of structures but also to identify patterns of thinking and difficulties they might have. To do this we built a network of features. A bar in the network (see Figure 8.1) describes a response in terms of the choice of only one feature (A or B or C) and a bar labelled as *R* describes a response in terms of the choice of one or more features (A and/or B and/or C). A bracket provides for descriptions in terms of all its features (A, B and C).

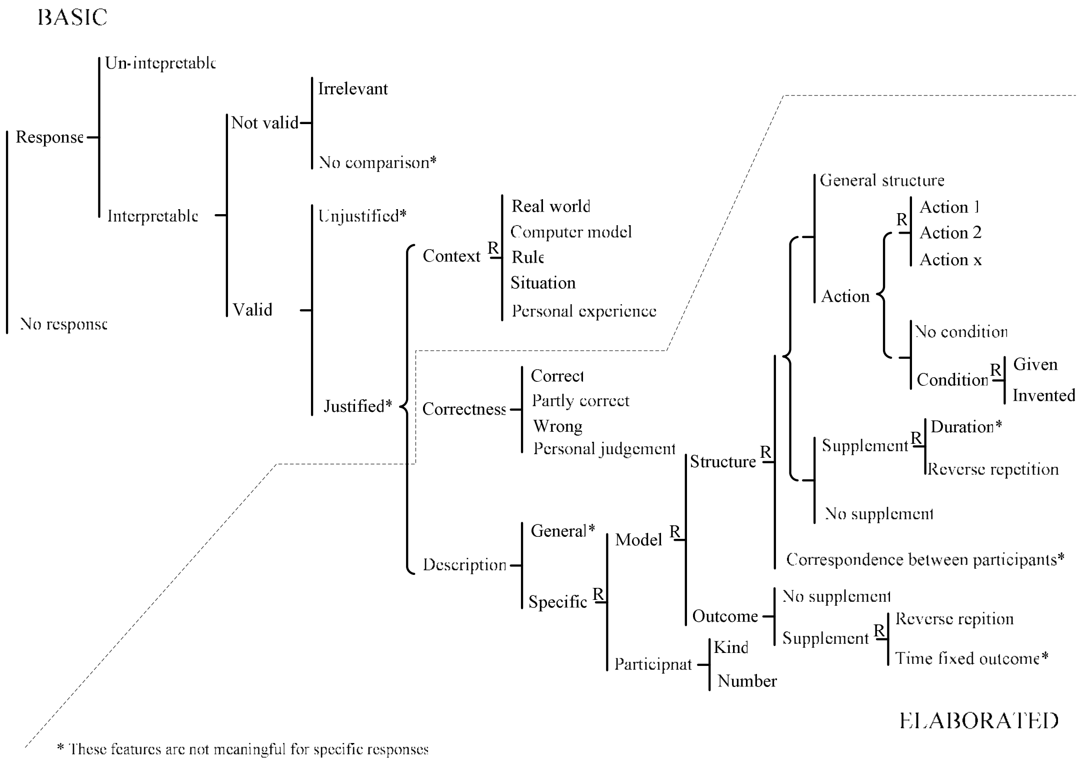


Figure 8.1 – Network for analysing the children's responses

The features presented in the network are basic or elaborated. The basic features provide an outline of a response:

- o Is it an interpretable response?
- o Is it valid?
- o Is it justified?
- o What is its context?

The elaborated features give a more detailed description of a response:

- o Is it correct?

- o Is it a general response or a specific one?
- o Is it about the model and/or the participants?
- o Is it about the structure of the model and/or its outcome?
- o Is it about correspondence between participants and/or actions/general structure?
- o Does it describe any conditions for the actions presented?

The meaning of these features will be described later when each of them is analysed.

During the process of evolving and refining the network, Richard Boohan and Prof. Jon Ogborn (my supervisor) played an active role. Lists of responses were given to them (fifteen for each question and provided by different children across the different questions) and every time a network was constructed, they checked its reliability and where necessary suggested further refinements. Besides, for each network discussed, all the ‘problematic’ responses (responses not able to be represented by the specific network) were taken into consideration. For the final refinement of the network, which took place after part of the analysis had already been carried out, all responses were considered again. For each feature/category of the network, responses were given which were used as prototypes. In this way, care was taken that the network gave a framework for building a fair and complete picture of all the responses.

8.2.1 Overall results

The total number of responses differs from one part of the analysis to another, since certain features are only relevant to some questions. My principle is to report percentages of replies of a given kind out of the number of responses that could have been of that kind. It might be helpful to clarify this here.

8.2.1.1 Proportion of responses for each feature

If all the children had responded to all the questions, a total number of 4098 responses would have been collected. But as a number of children were absent for some tasks, the maximum total number of responses was 3460.

In subsections 8.2.1.2, 8.2.2 and 8.2.3 the responses to 34 out of the 37 questions are considered (the other 3 questions are dealt with in sections 8.3 and 8.4). Taking this into account, the maximum total number is 3137.

When the children replied to a question they might give 'double' responses. This was very rare (a total of 43 'double' responses to a single question), and it was decided to include these as separate responses in the rest of the analysis. They were few enough in number not to alter the general trends detected. These take the maximum total number from 3137 to 3180.

During the analysis certain categories of responses have been excluded at particular stages:

- The children sometimes did not respond to certain questions of a research task and the total number of responses collected was 2971. Thus the total number of responses to be considered as being 'interpretable'/'un-interpretable' was 2971.
- 254 of the responses collected were 'un-interpretable' and thus the number of responses to be considered as being 'valid'/'not valid' becomes 2717, for the reason that a response that does not make sense cannot be considered as being 'valid'/'not valid'. In addition, to calculate the 'no comparison' responses' proportion, the 349 responses to group A (description of a story or a computer world) have to be eliminated because they do not allow any possible comparison.
- The total number of 'not valid' responses was 269, thus there were 2448 'valid' responses to be considered as being 'justified'/'unjustified'. Looking for the proportion of 'unjustified' responses, the responses to the descriptive questions also did not count (341 'interpretable' descriptive responses), as it is meaningless to consider justification in a descriptive response.
- 327 responses were 'unjustified'. Thus looking for the context of a response and its correctness, the 'unjustified' responses were not considered and the total number of responses becomes 2121.

- o When considering the 'general' responses – which do not apply to the descriptive ones – 341 descriptive responses were taken out. The total number of responses becomes 1780.
- o The total number of 'general' responses was 241. In the case of the 'correspondence between participants' responses, the 341 descriptive responses as well as the 'general' responses did not count and the number of responses becomes 1539.
- o In all the remaining categories, where the responses to all descriptive (group A), comparative (group B, C, D, E and F) and predictive (group G) questions count, the 'general' responses were excluded and the number of responses becomes 1880.

8.2.1.2 Frequencies of 'interpretable', 'valid' and 'justified' responses, and use of context

The children's tendencies to respond to questions, to provide 'interpretable', 'valid' and 'justified' responses as well as the context of the children's responses are presented next.

- Did the children respond to the questions?

  The tendency not to provide responses was small and very similar (between 2% and 4%) for the 'Cats', the 'Diseases' and the 'Cat/Disease' tasks, but was much stronger in the case of the 'News' task (13%) and quite large in the case of the 'Disease/Rumour' and the 'ABC' tasks (8% in both cases). The questions to which the children most often responded come from the 'Cats' task, which is about an 'unrealistic' situation (however these were also the first ones asked).

- Did the children give 'interpretable' responses?

  The average proportion of 'un-interpretable' responses varies somewhat, being large for questions about the 'Disease/Rumour' task (15%) and lowest for the 'Cats' one (4%). As above, the children provided 'interpretable' responses although they worked on an 'unrealistic' situation.

- Did the children give 'valid' responses?

When the children were dealing with the ‘ABC’ task, they had the strongest tendency to provide ‘not valid’ responses (19%). In that case, the children were provided with a set of ‘abstract’ rules and they had to decide if specific states of the computer world were possible. The children had some difficulties in considering the ‘abstract’ rules and the states of the computer world at the same time. They often dealt only with one, the computer world or the rules, (12% of ‘no comparison’ responses) or they reflected on only one and actually responded to a different question (7% of ‘irrelevant’ responses). On the other hand, when responding to the ‘News’ task, only 2% of their responses were ‘not valid’.

- Did the children give ‘justified’ responses?

  The proportion of ‘unjustified’ responses was very high when the children responded to questions coming from the ‘Cats’ task (33%). The reason may be that they found it difficult to say why a situation that made little real world sense was or was not sensible. They could decide whether it made sense, but not justify their decision.

- What was the context of the children’s responses?

  The children were asked to consider four different kinds of contexts (rules, stories, computer worlds and the real world) in the tasks presented to them. When they described a story or a computer world, then the ‘valid’ and ‘justified’ responses they provided came from at least one context. In all the other cases – when asked to make comparisons and predictions – the children had to refer to at least two different contexts.

  When responding to all the tasks, the children mainly considered only the piece of information suggested by the questions. The additional contexts that they drew upon were the real world, their personal experience or a story. When not asked, the children never invoked the information in rules or computer worlds. In general, the children’s tendency to invoke the real world as an additional source of information was stronger than their tendency to refer to their personal experience (for example, a response like “I just know it”) or to the content of a story. The group of questions where this tendency was the strongest (15%) included all the questions asking for comparison of participants. It seems to be the case that when the children were asked to compare participants having a real world ‘identity’ known to them, then the real world was the most likely candidate for an additional source of information. When the children were asked to compare a story or a computer world with real life by answering questions like "*Does this story make sense?*", their tendency to reflect on the real world was much stronger than their tendency to consider their personal experience.

8.2.2 Correctness and generality of responses

The children's responses are firstly considered in terms of their correctness and generality.

8.2.2.1 Correctness

When considering a child's response that is 'interpretable', 'valid', 'justified' and has a specific context/s, correctness is the first feature to be looked at in detail.

What is a 'correct' response?

A 'correct' response is one that includes no false information, no information that is not in accordance with the context of a question. If the question is "*Does this story* (i.e. 'Nuclear accident') *make sense? Why?*" one response might be "Yes, this story makes sense because the people heard about what happened and they became informed" and another might be "Yes, this story does make sense because it tells you that the news at 6.00 o'clock spread the news". Both responses are 'correct' even though they focus on different aspects of the story. In that sense there is no single 'correct' response for any question.

If a response is not 'correct' it can be 'partly correct', 'wrong' or 'personal judgement'. A response is 'partly correct' when it includes some information which is correct, although there is some which is wrong. A 'partly correct' response to the question above might be one like "Yes, the story does make sense because when something happens everybody does get informed by listening or watching and then they know". Everything the child claims is correct except that only most of the people (not everybody) in the story get informed about the accident. A response is 'wrong' when there is no correct information in it. Such a response is one like "No it doesn't, because everybody would want to know about a serious accident like … not get bored with it". It is 'wrong' because the child argues against a fact that is not in fact in the story – the information that the people become bored after listening to the news.

Nevertheless, there is a case ('personal judgement') in which it is not possible to decide whether a response is 'correct' or not. In a response like "Yes, it makes sense because I understand it", children provide a personal justification which is neither correct nor wrong.

On the whole, the majority of the children gave responses that were 'correct' (79%). Only 7% of them were 'wrong', 10% were 'partly correct' and 4% were 'personal judgement' responses.

Variations of 'correct', 'partly correct', 'wrong' and 'personal judgment' responses within questions of the same group

Was the children's tendency to provide 'correct', 'partly correct', 'wrong' and 'personal judgement' responses the same across questions of the same group? As Figures 8.2, 8.3, 8.4 and 8.5 show, when the children compared stories (group B), participants (group E) and rules (group F) they had a similar tendency to provide 'correct', 'partly correct', 'wrong' and 'personal judgement' responses. By contrast, when the children described a story or a computer world (group A), compared a story to a computer world (group C), compared a story or a computer world with the real world (group D) and when they predicted the outcome of 'abstract' rules (group G), the children's tendency to provide 'correct', 'partly correct' and 'wrong' responses varied a lot across the different questions. In the case of the 'personal judgement' responses, excluding the questions of group D (especially the first two questions from the 'Cats' task), the children had a similar tendency across questions of the same group.

Group G had the lowest proportion of 'correct' responses. In this case, the children were provided with the pictures of rules, thus they had to use the WM formalism to make their predictions. Not surprisingly, this ended up not being an easy task for them.

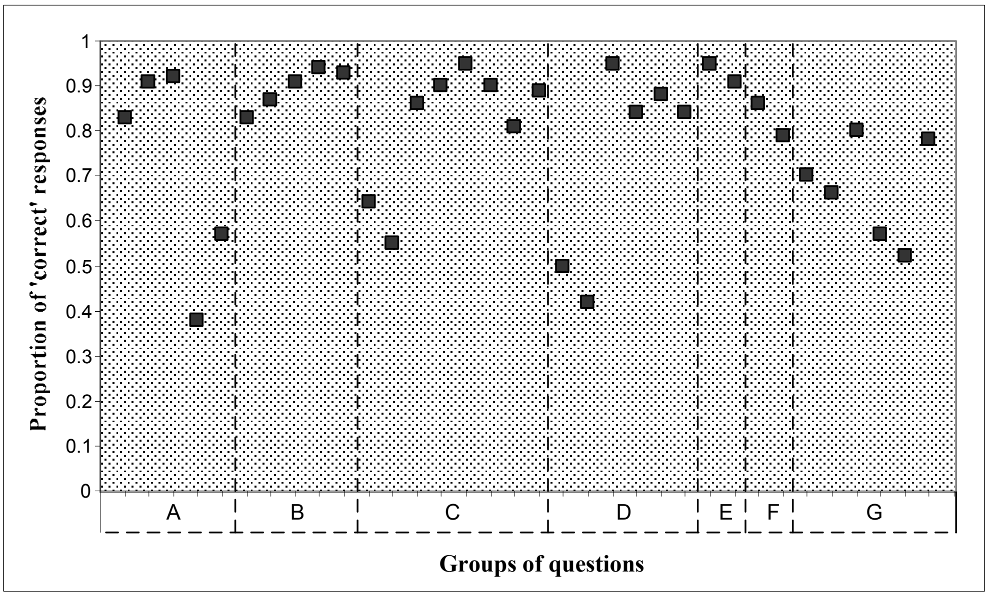


Figure 8.2 – Proportion of 'correct' responses for each question

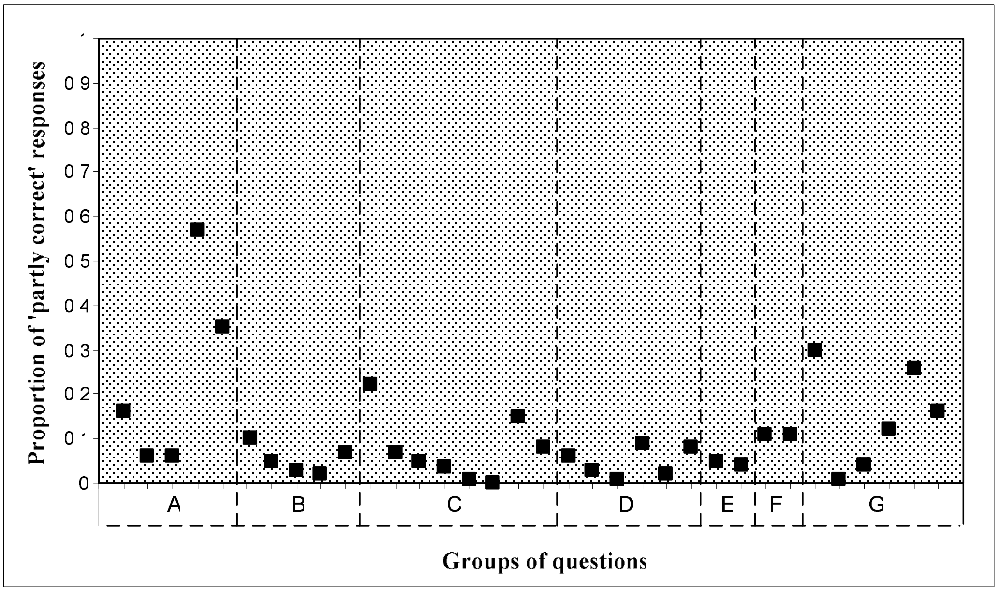


Figure 8.3 – Proportion of 'partly correct' responses for each question

When the children responded to questions asking them to describe a story or a computer world (group A), in the last two questions ("*How did the secret spread in the party? In the end, did everybody know about it?*" and "*How did the news about the nuclear accident spread? In the end, did everybody know about it?*") they did not provide 'correct' responses as often as when they responded to the rest of the questions of this group. They provided more often 'partly correct' responses. This was due to the fact that these questions ask children to specify the number of the participants in a story, a task that proved not to be so easy. The children were confused with the terms 'most' and 'everybody'.

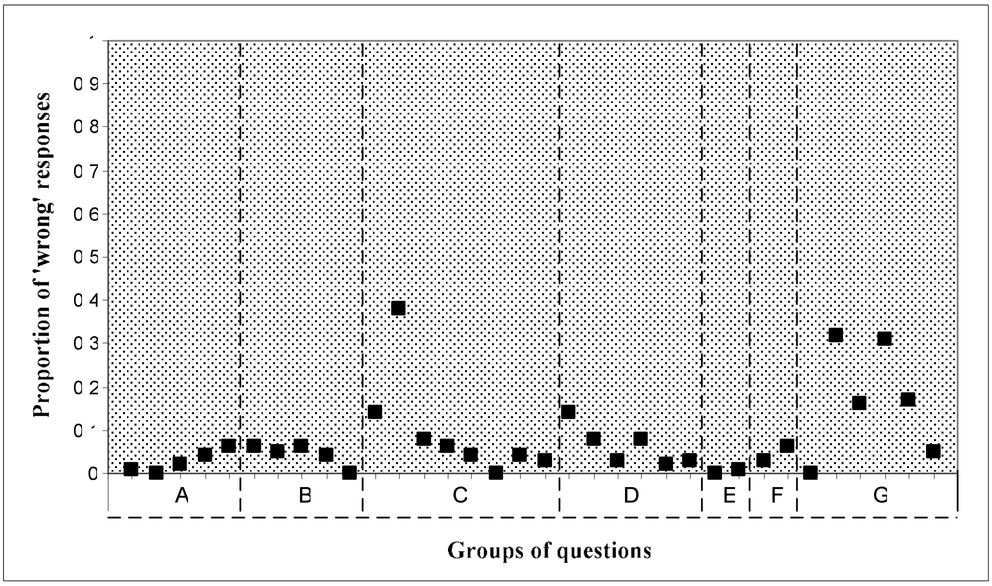


Figure 8.4 – Proportion of 'wrong' responses for each question

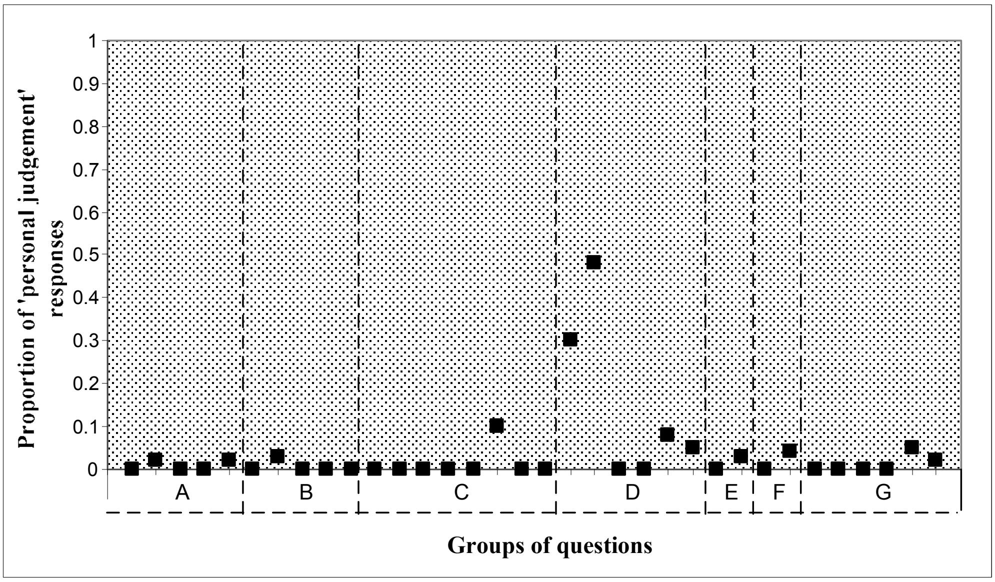


Figure 8.5 – Proportion of 'personal judgement' responses for each question

From Figures 8.2 and 8.5 we can see that when the children responded to questions from the 'Cats' task they had a different tendency from the other questions of the same group to provide 'correct' and 'personal judgement' responses. When they were asked to compare the 'Cats' story to the 'Cats' computer world (the first two questions of group C: "*Is what happens in the story* (i.e. 'Cats') *like what happens in the computer world? How?*" and "*Are they different in any way?*") and each of them with the real world (the first two questions of group D: "*Does this story* (i.e. 'Cats') *make sense?*" and "*Does this 'world' make sense?*"), they had the weakest tendency to provide 'correct' responses. The last two questions were also related to the strongest tendency for 'personal judgment' responses. It seems to be the case that the children had some difficulties in dealing with an 'unrealistic' situation. Overall, in the case of the 'Cats' task you get fewer 'correct' and more 'personal judgement' responses whichever group of questions they appear in. We will see later in the analysis that there are other aspects in which the questions of this task do not work well.

Summary of results

Overall the proportion of 'correct' responses was high and if 'correct' and 'partly correct' responses are taken together, it becomes very high. The 'ABC' task was the hardest one, but the proportion of 'correct' responses was still quite high (50-80%), in view of the fact that the children had to predict the outcome of 'abstract' rules. In addition, they had difficulties when they responded to questions about an 'unrealistic' situation ('Cats'), but at the same time the 'unrealistic' situation encouraged them to express their personal and unique judgements about it.

8.2.2.2 Generality

The next step to be taken is to reflect on whether a response includes a general statement or references to specific characteristics of a situation. The 'general' responses are these which are not sufficiently clear or specific to be assigned a detailed feature of the network. These were therefore excluded from the part of the analysis that describes responses in terms of specific features.

What is a 'general' response?

A child's 'valid' and perhaps 'correct' response might not address the actual details of a model, remaining at the level of a very general, non-specific view of the model. For example, "… John's party is a party and this is about an accident".

By contrast, the children were able to give more specific reasons, which have something to do/relate to how situations or computer models work. For instance, "I think both of them have something to spread and both of them are sort of like news and secret".

From the point of view of involving children in making, evaluating and thinking about WM models, the second (specific) type of response is more encouraging. The 'general' responses, while not necessarily incorrect, do not engage with processes that need to be thought about from the modelling perspective. In particular the 'general' responses provide no evidence of children's appreciation of the structure of a model, which is needed if models are to be compared or analysed. These responses cannot be labelled with specific features that illuminate the way children think. One would therefore hope that a majority of responses are specific in some way, rather than being purely general (as defined here).

Here are a few more examples of 'general' responses:

- "It makes perfect sense. Yes it does, because it just makes the creature do the same thing";
- "Yes, it is quite like the story because of the way the moving balls all change";
- "Yes, because each step by step is the same";
- "No, it is different, because the sick school child story is like the computer story";
- "Yes, because the rules of a 'diseases' world are in pattern with a 'rumour' world"; and
- "The only difference is that it is a disease and not a gossip".

As it turned out, on average, overall 14% of the children's responses were 'general'.

Variation of 'general' responses within questions of the same group

Was the children's tendency to provide 'general' responses the same across questions of the same group? Figure 8.6 shows the proportion of 'general' responses for each question excluding the questions of group A, because it is not possible to have 'general' responses when children are asked to describe a story or a computer world.

One must be careful not to over-claim for the absence of 'general' responses. In cases where questions clearly ask children to give specific details, is much more likely that they will do so. This is the case for all the 'ABC' task's questions (group G), for which the proportion of 'general' responses was indeed low for all the questions. However, as noted in subsection 8.2.2.1 these responses were rather more often 'wrong' than for other questions generally.

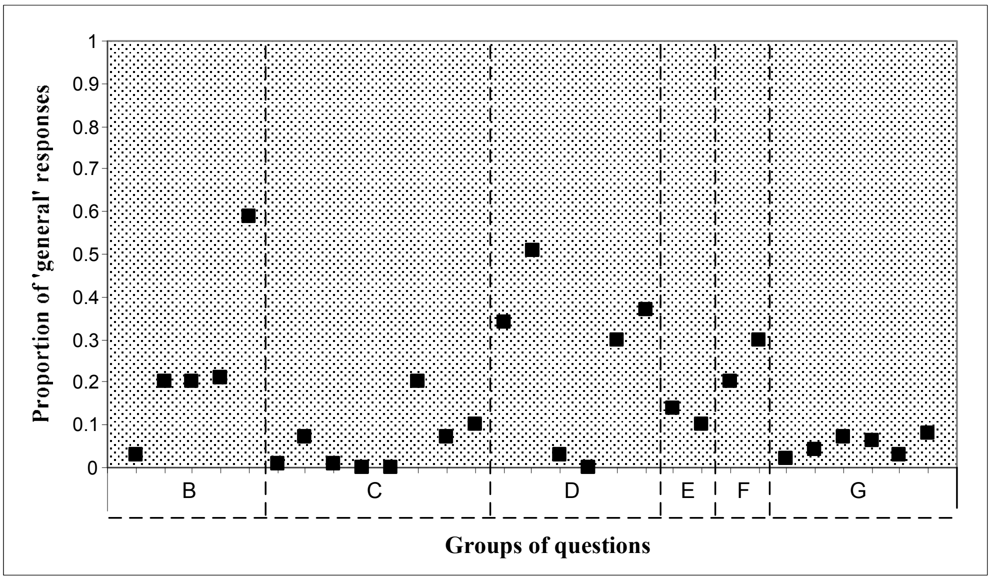


Figure 8.6 – Proportion of 'general' responses for each question

The two questions in group E ("*Is the ill person like the informed person in any way?*" and "*Is the cat like the healthy person in any way?*") also strongly encouraged specific responses. As expected, the proportion of 'general' responses was quite low.

A particularly interesting special case is the last two questions in group B: "*Is what happens in the story about diseases the same as what happens in the story about rumour? How?*" and "*In what ways is it different*?". The first (similarities) had only 20% 'general' responses, but the second (differences) was answered generally by a majority (almost 60%). The most common 'general' response here accounted for the differences in terms of the context in the stories. This may be understandable in terms of the fact that the two stories compared actually do have the same model structure, so that differences are rather naturally attributable to the context. Thus, this is a case where 'general' responses are rather appropriate, and do not indicate a failure to address the specific aspects of a model.

Furthermore, four questions asked whether a story, or, in some cases, a computer world, '*makes sense*' (group D). In each case the proportion of 'general' responses was quite large (30% to 50%); a typical kind of response was "No, because these things don't happen in real life". Again, these appear to be cases where a 'general' response is perfectly adequate. This accounts for the high proportion of 'general' responses in group D (comparison of stories or computer worlds with the real world). By contrast, when the children were asked to compare a story or a computer world with the real world in the third and fourth questions ("*Is what happens with real diseases like what happens in the computer world?*" and "*Can you think of something that happens in real diseases but doesn't happen in the computer world?*"), they hardly ever provided 'general' responses.

Finally, when the children were asked to compare rules (group F), they had a fairly strong tendency to provide 'general' responses (25%). As it turned out, the children were not willing to reflect on the actions pictured in the rules they had drawn before or in the participants. This might not be an encouraging result regarding the children's modelling abilities. Although they were asked to focus on rules, which are the pictorial representations of structures, a considerable percentage did not see rules and structures as closely related. Thus, one should have a second thought when designing activities and tasks aiming to encourage children's involvement in the modelling process. But, some might say that the fact that the children had to draw the rules probably was an obstacle in looking at structures. Even though the research data available cannot help in making a straightforward comparison – the children were not asked to compare rules drawn by someone else –, there are some indications that probably that was not the case. When the children accomplished the 'Disease/Rumour' task (the last two questions of group B and the first question of group E), in which the pictures of rules were provided, their tendency to provide 'general' responses was no less strong.

Summary of results

Overall, the 'general' responses were less than 20%. For the few cases in which there were high proportions of 'general' responses, in most cases one can find a reason. In these cases the high proportions were related to the questions, where a 'general' response looks more reasonable. Furthermore, when the children were dealing with rules, they were not encouraged to provide 'specific' responses.

8.2.3 Detailed profiles of responses

In this subsection, I am going to take the questions in each group and for each group to compare the proportions of the elaborated features. The point of the profiles is to look for a pattern of 'specific' responses for each group of questions. First, I shall define some of the elaborated features.

8.2.3.1 Definitions of elaborated features

The network describes the following important elaborated features of the responses:

- Action;
- Condition;
- General structure;
- Correspondence between participants;
- Model outcome; and
- Participant.

Each of the elaborated features is firstly defined and exemplified. The responses will then be discussed group by group for the groups of questions A to G – in terms of the question to which they are related – and across the different features. Finally, 'action' responses will be considered separately since across all the groups of questions they indicate children's basic understanding of the structure of a model and of the changes included in it.

Action

The term *action* in the network describes changes of an object, which do not necessarily include a condition. Three different types of action might be included in children's responses. In 'action 1' an object A changes to an object B under specific conditions (whether mentioned or not); in 'action 2' an object A changes by itself to object B. The changes from cats to dogs, from ignorant to informed, from healthy to ill and from A to B are called 'action 1'. 'Action 2' are the changes from dogs to mice, from informed to bored, from ill to better and from B to C. The description of any other change that is not included in any of the stories or computers worlds provided, and so is one invented by children, is called 'action x'. Then, 'action 1' is about a conditional change, 'action 2' about an autonomous and 'action x' about an invented one.

If the question is "*How does the news spread in the computer world? In the end, have all unaware persons changed to informed?*" a response might be "There were three unaware persons. I put three informed persons and all the unaware persons turned into informed. After, those informed persons turned themselves into bored persons", or "If Informed touches Uniformed it will change to Bored and if Informed touches Bored it will change to Bored". In the first case, 'action 1' as well as 'action 2' is invoked for the description of the specific computer world, while in the second, there are two invented actions ('action x').

Here are some more responses in terms of 'action 1' and 'action 2':

- "No, I don't think it does make sense. I don't think cats turn to dogs, then mice." ('action 1' and 'action 2');
- "Healthy people became ill and then ill people became better." ('action 1' and 'action 2'); and
- "Yes, because they start off healthy or ignorant, then they get ill or informed, then better or bored." ('action 1' and 'action 2').

Condition

The description of an action may be accompanied by pieces of information about the conditions under which the action takes place. In this case children show evidence of more understanding of models.

Reflecting on the conditions of an action, children might provide 'given' or 'invented' responses. Answering the question "*How does the disease spread in the computer world?*" children might provide responses like "When healthy people touch ill people they get ill. Then when ill people touch ill people they get better". In this case, children do define the necessary condition for a healthy person to turn to an ill one ('action 1') and for the ill person to become better ('action 2'). Only that the first condition is the one given by the 'Diseases' task, while the condition related to 'action 2' is invented. In this case, it is good because the children saw the need for a condition, but it is less good because the condition was not correct in the given model.

General structure

When the question is "*Is the ill person like the informed person in any way?*" responses might be "Yes, because you start with one thing and it becomes another" or "Yes, the ill person is like the informed person, they both get something off the other person". In both cases, the children gave a very broad and global description of the actions. An 'action' response like "Yes, it is because informed people make ignorant people informed people and ill people make healthy people ill people" would be rather better.

The following responses are also 'general structure' ones:

- "No, because no animals change into another thing";
- "The diseases spread with germs";
- "The disease is transmitted"; and
- "… The news spread by people meeting and talking".

Correspondence between participants

If the question is "*Are your 'cats' rules similar to your 'diseases' rules? In what ways?*" a response might be one like "Before there are Cats-Cats and in diseases Healthy-Healthy, then it is Dogs-Dogs and Ill-Ill, then ...". The children compared the two pairs of rules provided to them and they found them similar. The participants in one of the rules corresponded to the participants in another because they appeared in the same cells in the 'before' and/or 'after' pictures of the rules. Although, the children did not consider the changes pictured in the rules, they showed an understanding of the structure of the model.

Here are some more cases of 'correspondence between participants' responses:

- "Yes, because the ill person appears at the same spaces as the informed person";
- "Yes, because the H and I are the same and then ill and informed are the same and the better and bored are the same"; and
- "No, all the C's should be in the after box, not before".

Model outcome

If the question is "*Is what happens in the story about diseases the same as what happens in the story about rumour? How?*" a child might consider the outcome of the situations, providing a response like "... and for the diseases story you got better, in the rumour story you got bored". This response is reasonable and it refers to what happens rather than to why it happens. In this case, the children did not focus on the different changes included in the model, but on a ‘global’ action of the type ‘A and B/everything changes to C’ where A and B stand for all the objects participating in the initial change and C for the object that is the outcome of the final one. Although no description of the model was provided, the children did show an understanding of its structure at least in terms of the final change included in it.

These are a few more responses about the outcome of a model:

- “No, because the cat and dog became mice”;
- “In the real world some people die after a disease, but they don’t die in the computer”;
- “No, it is not the same, because at John’s party people got bored, but in the nuclear accident they didn’t get bored”; and
- “It is different as thousands of people know all about it”.

Participant

Reflecting on the participants, children might consider their kind and/or their number. If the question is “*Does this story* (i.e. ‘Nuclear accident’) *make sense? Why?*” a response might be “Yes it does, because some people worked at nights and sleep in days and some people wake up so late. So this story does make sense”. In this response the children focused on the fact that even though the nuclear accident took place in the morning, people heard about it late in the afternoon. Thus, they provided a justification for the kind of the participants (uninformed) in the situation (uninformed becomes informed by listening to the news). In this case, the children were relying on their ideas about the participants and not on how they function within the rules of the model. This reasoning is at the edge of what reasoning about models might be. From there, children can move towards rules and modelling.

The next responses are a few more cases where the children focused on the participants of a model:

- “No, in the computer everyone became ill from one person. In the story the boy was strong enough not to catch the flu”;
- “They are both different stories, because they are based on different things, e.g. better, bored”; and

- o “No it is not the same, because the cat is animal and the healthy is people. So, this is different”.

When deciding if the ‘Nuclear accident’ story ‘makes sense’, a different response might be one like “No because every one should know, it is important”. This response is about the number of the participants, because the persons that do not participate are the ones that do not know at the end. If someone participates, then he/she becomes informed.

A few more responses about the number of the participants, which are ‘action’ responses as well, are given below:

- o “There were 3 healthy people, I put 3 ill people. Slowly they all became ill, then all of them got better”; and
- o “There were three unaware persons, I put three informed persons and unaware persons turned into informed persons. After that, informed persons turned themselves into bored persons”.

8.2.3.2 Analysis by groups of patterns of elaborated features

In the main part of the analysis, each group of questions is considered individually in order to compare the profiles in it.

Group A – Description of a story or a computer world

This group of questions was designed to find out whether children are able to tell about the mechanism of a situation, to give an account of the action of ‘spreading’. A perfect answer for these questions is to describe the ‘spreading’ action at least in terms of the actions that take place and their conditions. There are five questions in this group (see page 135); the first two questions are included in the ‘Diseases’ task and the remaining ones in the ‘News’ task.

According to Table 8.1, for the first two questions (Diseases.1 and Diseases.2) we got rather similar patterns of responses. Nearly all of the children focused on actions, half of them on conditions and most often their responses were ‘correct’. In the first question, the children focused on the participants’ number without being asked to do so. The third question (News.1) was also very successful with a similar pattern of responses. For the last two questions (News.2 and News.5) there are still many responses about action and quite a lot about condition but the frequency of ‘correct’ responses was lower than all the other questions of the group (38% and 57%, respectively). This was because the children very often talked about the number of the participants in the stories as they were asked to respond to the question “*In the end, did everybody know about it?*” but their estimation was not correct – but only by understanding ‘most’ as meaning ‘everybody’ (see subsection 8.2.2.1). Thus, probably this fine lexical distinction for children of this age was meaningless. By contrast, for question News.1, even though the children were asked as well to specify the number of participants in a computer world – “*In the end, have all unaware persons changed to informed?*” –, they did not do so very often. Surprisingly, the children considered more often (83%) the number of the participants when they looked at stories (News. 2 and News. 5) than (20%) at a computer world (News. 1). Although they could enumerate the participants when they observed the events taking place on the computer screen, they most often worked from the written description, using rather unsuccessfully the relatively fine verbal distinctions of ‘most’ from ‘everybody’.

	Diseases.1	Diseases.2	News.1	News.2	News.5
Correct	83%	91%	92%	38%	57%
Action	85%	90%	90%	89%	86%
Condition	53%	55%	41%	74%	86%
General structure	12%	6%	2%	6%	0
Correspondence between participants	N/A	N/A	N/A	N/A	N/A
Model outcome	4%	3%	0	15%	14%
Kind of participants	3%	3%	0	0	0
Number of participants	19%	1%	20%	80%	86%

Table 8.1 – Proportions of elaborated features for responses of group A

Overall, the children managed quite well, although these questions were not designed to be difficult. There was a strong focus on actions and conditions of actions. Thus if the children were asked to make a computer model, they would have been thinking in the right kind of way to build a WM model.

Group B – Comparison of stories that seem similar but can have different structure

These questions try to find out if children are able to look at structures when they compare stories. The most preferable response is one where children identify actions and conditions of actions as being/not being the common elements for the compared stories. There are five questions of this kind about diseases and news; four of them come in pairs (see page 135). In each pair, one question asks about similarities and the other one about differences. Only in the pair of questions coming from the 'Disease/Rumour' task, the compared stories have common actions.

	Diseases.8	News.9	News.10	Disease / Rumour.2	Disease / Rumour.3
Correct	83%	87%	91%	94%	93%
Action	68%	48%	75%	50%	20%
Condition	43%	45%	61%	32%	0
General structure	24%	26%	0	29%	8%
Correspondence between participants	0	0	0	8%	4%
Model outcome	4%	23%	21%	11%	40%
Kind of participants	8%	0	7%	3%	28%
Number of participants	7%	0	4%	3%	0

Table 8.2 – Proportions of elaborated features for responses of group B

As Table 8.2 shows, there were large proportions of 'correct' responses in all questions. In the first question (Diseases.8), where what was happens in the story about Mary is not like what happens in the story about the sick school child, the children very often looked at actions and conditions. The pair of questions News.9 and News.10 asks children to identify, respectively, similarities and differences between two stories that do not share the same kind of action. Here the children's 'action' and 'condition' responses were as expected less frequent in the case of similarities than in the case of differences. By contrast, in the responses to questions Disease/Rumour.2 and Disease/Rumour.3 – the first of which asks for similarities and the second for differences between stories about diseases and rumour which share exactly the same model –, the children more often considered the outcome of the changes included in the stories and the kind of the participants in those changes, than the changes themselves, when they looked for differences (Disease/Rumour.3). Not surprisingly, they were not able to identify any difference in terms of the structure of the stories. As might be expected they provided more frequent 'action', 'condition' and 'general structure' responses when they looked for similarities (Disease/Rumour.2).

On the whole, the children mainly provided 'correct' responses when they compared stories but their responses did not always, and with the same frequency, fit the WM format. When there was a pair of questions, the children did not respond in the same way to the questions asking for similarities and those asking for differences.

Group C – Comparison of a story to a computer world

These questions look for the children's ability to focus on structures when they compare a story to a computer world. A perfect response is one where the similarities and/or differences between a story and a computer world are defined in terms of the basic elements of the description of a WM model, which are actions and conditions of actions. Eight questions belong in this group, coming from the 'Cats', the 'Diseases' and the 'News' tasks (see page 136). Six of them are in pairs – one asking for similarities and the other for differences.

	Cats.1	Cats.2	Diseases.3	Diseases.6	Diseases.7	News.4	News.7	News.8
Correct	64%	55%	86%	90%	95%	90%	81%	89%
Action	80%	33%	80%	71%	78%	54%	32%	50%
Condition	54%	4%	44%	33%	32%	42%	32%	55%
General structure	1%	4%	11%	14%	10%	15%	12%	0
Correspondence between participants	0	0	0	1%	0	11%	8%	0
Model outcome	5%	33%	11%	10%	0	23%	40%	30%
Kind of participants	4%	37%	1%	9%	12%	0	4%	9%
Number of participants	4%	0	0	0	1%	0	12%	9%

Table 8.3 – Proportions of elaborated features for responses of group C

We see in Table 8.3, that the first two questions (Cats.1 and Cats.2), asking children to compare the 'Cats' story with the corresponding computer world, were much less successful than all the other questions of the group, although this is one case of a pair of questions where the compared story and the computer world have the same structure. In the first question (Cats.1) that asks for similarities, most of the children focused on actions and a considerable number on conditions, but only 64% of their responses were ‘correct’. In the second question (Cats.2), looking for differences, the children found it too hard to focus on actions (as the story and the computer world share the same set of rules) and they focused with nearly the same frequency on the outcome of the model and on the kind of the participants. But still, both the story and the computer world have the same outcome. It seems to be the case that the children did not know how to handle this ‘crazy’ computer world and story where cats change to dogs when they meet each other.

With regard to the third question (Diseases.3) there was a pattern of responses rather similar to that for Cats.1, with the addition of a few ‘general structure’ and ‘model outcome’ responses. But in this case, the children were much more successful at an otherwise similar task. The responses to the fourth and to the fifth questions (Diseases.6 and Diseases.7) were again of a very similar type. In both cases the main focus was on actions and quite a few responses were about condition.

The patterns of responses to the last three questions (News.4, News.7 and News.8) were rather similar to one another. Most responses were ‘correct’. About half the responses were about action (rather less for News.7). Conditions were also quite frequently mentioned, and model outcome had some importance in all. It seems that here that all possible responses were attractive to at least some children. In questions about news, as in the case of diseases, there was a similar pattern of responses for questions from the same task even though they explore different kinds of relations between the story and the computer world. In the Diseases.3 and the News.4 questions, the same rules describe the stories and the computer worlds, while in Diseases.6 and Diseases.7 as well as in News.7 and News.8 the stories and the computer worlds are not about the same actions. Here, probably the type of response was more related to the context of the question (it can be about cats, diseases or news) rather than to the kind of relation between the story and the computer world that the question investigates.

Overall, most often the children managed these questions successfully (with one exception – Cats.2) and quite often focused on actions and conditions. There was a considerable tendency for the outcome of the model to feature in responses. It may be the case that preferences for action and outcome types of response were related. The lower the preference for action the higher the preference for outcome and the reverse. In the questions asking for differences the kind of the participants attracted the children's attention.

On the whole, the children managed to compare a story to a computer world in a WM way (in terms of actions and conditions of actions) with a varying frequency across the different questions. It is likely that the context of a question was related to the kind of response given.

Group D – Comparison of a story or a computer world with the real world

The questions given to group D were designed to make children think of the real world by asking them to compare it with stories and computer worlds. The most preferable type of response is one that is about the reality or not of what is needed to create a model; that is, actions and conditions of actions. Six out of the seven questions of this group (see page 136) are analysed here – the Cats.5 question is analysed in section 8.4. Four of them are phrased like "*Does this story or computer world make sense?*" and two like "*Is what happens ... like/not like what happens in the real world?*".

	Cats.3	**Cats.4**	**Diseases.4**	**Diseases.5**	**News.3**	**News.6**
Correct	50%	42%	95%	84%	88%	84%
Action	55%	55%	40%	50%	80%	63%
Condition	18%	16%	10%	30%	58%	58%
General structure	10%	8%	24%	4%	18%	0
Correspondence between participants	0	0	0	0	0	0
Model outcome	12%	3%	20%	56%	0	21%
Kind of participants	15%	18%	1%	6%	0	17%
Number of participants	0	0	1%	0	0	13%

Table 8.4 – Proportions of elaborated features for responses of group D

From Table 8.4 we see that when the children were asked to decide if the story and the computer world about cats make sense (Cats.3 and Cats.4, respectively), a considerable number of them focused on actions and just a few on conditions, but only about half of them succeeded.

By contrast, when the children compared what happens in real diseases with what happens in the corresponding computer world (Diseases.4 and Diseases.5), they were very often successful. The fact that children of this age are expected to be able to give an account of what happens in communicating real diseases could explain this level of success. Surprisingly and disappointingly from a modelling point of view however, the ‘correct’ responses were not very often ‘action’ and ‘condition’ ones. In the case of similarities (Diseases.4) most of the responses were about action and quite a few about the outcome of the model and its general structure. Looking for differences (Diseases.5), ‘action’ responses were nearly as frequent as before, but ‘general structure’ responses were very rarely provided and ‘model outcome’ responses were much more frequent.

When the children responded to question News.3 (“*Does this story* (i.e. John’s party) *make sense? Why?*”), they often gave a modelling type of answer. That is, they reflected on the actions, the conditions and the general structure. The children’s responses to the last question News.6 (“*Does this story* (i.e. ‘Nuclear accident’) *make sense? Why?*”) were much more varied. As the children were removed from anything they knew well – the spreading of news about a nuclear accident is not part of their everyday knowledge – most of them looked to see if the actions and the conditions made sense. Some focused instead on the model outcome and on the participants. Variations in the frequency of responses about general structure, model outcome and participants suggest some degree of context dependency here (familiar and unfamiliar stories).

It seems that the questions from the ‘Cats’ task were hard for the children while the rest of the questions worked quite well. There was generally a considerable focus on actions, but not as much as for other groups of questions. Condition was always chosen by some children, but not always very often. The tendency to give ‘general structure’ or ‘kind of participants’ responses was generally quite low, but variable, much the same as for ‘model outcome’. The correspondence between the participants and the number of the participants were never considered.

On the whole, in comparing stories or computer worlds to the real world, the children rather often gave ‘correct’ responses except where the situation was ‘crazy’, and at least in half of their responses they mentioned the main ingredient of modelling with WM, namely actions. The amount of attention they gave to other features seems to be rather context dependent, suggesting that they judged the realism of a story or a computer world by a variety of criteria, selecting different ones as salient in different cases. There is nothing unreasonable about this from a modelling point of view, but the varied pattern of responses does suggest that in teaching using models one would need to be rather careful about the variety of ways in which a model might be judged true to reality or not.

Group E – Comparison of participants that have similar behaviour

The group E questions were designed to make children think of participants in terms of the actions they perform (see page 137). For the most appropriate ‘modelling’ response, one should mention at least the kind of changes that the participants undergo and the conditions for these changes.

	Disease/Rumour.1	**Cat/Disease.3**
Correct	95%	91%
Action	57%	48%
Condition	33%	22%
General structure	21%	29%
Correspondence between participants	8%	7%
Model outcome	0	0
Kind of participants	17%	15%
Number of participants	0	0

Table 8.5 – Proportions of elaborated features for responses of group E

From Table 8.5 we see that both questions were answered in a similar way. The children were quite successful in comparing the participants and in about half of their responses they focused on actions. Although in other questions actions were chosen more often, these questions were expected to be hard for children because the participants come from different stories, thus the abstraction that needed to be made could be quite demanding. Besides, at least in the case of the 'Disease/Rumour' task, the children had to consider the rules describing the actions performed by the participants.

The children had a wider point of view than one focused just on the WM 'modelling' way. Thus, they also focused on the general structure of the model and on the kind of the participants.

These results suggest that when teaching modelling to young children it is quite safe to ask them to focus on participants. Children will succeed, as they do not invoke the different nature of the participants – an attitude we would probably expect considering their age. But, they do not focus only on the kind of changes the participants undergo and the conditions for these changes. A considerable number of them reflect on the general structure of the model and the correspondence between the participants. Thus, when asking children to look at participants, it is expected that they will suggest different ways of looking at the changes in which the compared participants are involved, and quite a few of their responses will not be the most appropriate WM-like 'modelling' ones.

Group F – Comparison of rules that have similar structure

This pair of questions was designed to make children think of structures when they compare rules (see page 137). An ideal response to these questions compares rules, at least in terms of the actions and conditions of actions they incorporate.

Table 8.6 shows that the children often provided 'correct' responses. When they were asked to look at similarities (Cat/Disease.4) they only considered the actions, the general structure of the model and the conditions – an appropriate pattern of response. Looking for differences (Cat/Disease.5), the children focused on actions less often than in the previous question, but they looked at the outcome of the model as well as the kind of the participants. It might be the case that – as before in group C –, when the children were asked for differences and the compared rules had the save structure, then they considered other aspects of the rules such as the kind of the participants. It is a surprise that although they had been asked to draw the rules, they did not compare them in terms of the correspondence between the participants.

	Cat/Disease.4	Cat/Disease.5
Correct	86%	79%
Action	56%	24%
Condition	15%	3%
General structure	30%	0
Correspondence between participants	0	0
Model outcome	6%	33%
Kind of participants	0	38%
Number of participants	0	0

Table 8.6 – Proportions of elaborated features for responses of group F

On the whole, regarding the children's responses to the group E and F questions, the pictures of rules, although they were not a problem for the children, did not seem to encourage them to focus on changes more often than all the other cases. Perhaps when teaching modelling one should give more thought to which stage to introduce children to the pictorial representation of a rule.

Group G – Prediction of the outcome of 'abstract' rules

The questions of this group aim to make children think about rules expressed in abstract form (see page 137). The most desirable response is one where children focus on the necessary specific aspects of the 'abstract' rules – action and/or condition – when they decide whether some computer worlds work according to these rules.

From Table 8.7 we see that the children's responses to all the questions were mainly about action and condition. Not surprisingly, as they were here for the first time mainly asked to predict the outcome of 'abstract' rules, the 'correct' responses were not as frequent as in all the other groups of questions. But it was a surprise that the children were least successful when they replied to the fourth and fifth questions (ABC4. and ABC.5). Both are related to the 'Change' rule.

	ABC.1	ABC.2	ABC.3	ABC.4	ABC.5	ABC.6
Correct	70%	66%	80%	57%	52%	78%
Action	75%	82%	70%	78%	79%	93%
Condition	77%	35%	57%	44%	39%	52%
General structure	0	4%	0	4%	0	0
Correspondence between participants	0	3%	9%	9%	5%	2%
Model outcome	1%	0	5%	4%	5%	2%
Kind of participants	0	0	0	0	0	0
Number of participants	1%	0	1%	0	1%	0

Table 8.7 – Proportions of elaborated features for responses of group G

In answering the first and the third questions (ABC.1 and ABC.3), both actions and conditions of actions need to be considered. The children provided the appropriate patterns of responses and conditions were more often considered in those than in the other questions. To reply to the rest of the questions children need only to focus on the actions. They generally did so, although a few focused on the conditions as well; however the patterns of responses were appropriate. It can be noted that the children did indeed tend to focus on conditions when they needed to.

On the whole, the children were successful in dealing with 'abstract' rules and their responses were appropriate for the questions.

8.2.3.3 'Action' responses

Action was one of the main characteristics we were looking for in the children's responses as an indication of their understanding of the underlying structure of a model. In the stories and computer worlds presented to the children, two different actions were included. It was 'action 1' about the change of an object A to an object B under specific conditions and 'action 2' regarding the un-conditional change of an object. If the children talked about any other action – not included in the stories or the computer worlds presented to them – this was called 'action x'.

Table 8.8 below shows the proportions of 'correct', 'partly correct' and 'wrong' responses, which were 'action' responses as well, across the different groups of questions. To calculate these, the ‘un-interpretable’, the ‘not valid’, the ‘unjustified’ and the ‘general’ responses were excluded.

Group of question	**‘Correct action’**			**‘Wrong and partly correct action’**	**‘Action’ overall**
	Only one ‘correct action’		**More than one ‘correct action’**		
	‘action 1’	**‘action 2’**	**‘action 1’ & ‘action 2’**	**‘action x’ ‘action 1’ & ‘action x’ ‘action 2’ & ‘action x’**	
A	49%	2%	35%	2%	88%
B	47%	3%	6%	1%	57%
C	33%	1%	26%	9%	69%
D	21%	6%	15%	13%	55%
E	35%	2%	12%	2%	51%
F	15%	3%	15%	5%	38%
G	16%	18%	19%	27%	80%

Table 8.8 – Proportion of ‘action’ responses for each group of questions

According to Table 8.8 above, the children focused on actions when they were clearly asked to do so. In one case they had to describe a story or a computer world by describing the mechanism of the ‘spreading’ action regarding diseases and news (group A). In a different case (group G) they were asked to make predictions about the outcome of ‘abstract’ rules and inevitably any valid prediction had to be based on the actions pictured in the rules (88% and 80% of ‘action’ responses, respectively). At the same time, when responding to questions from group G, the children had the strongest tendency not to provide ‘correct action’ responses – i.e. ‘action 1’ and/or ‘action 2’ responses – (27% of ‘wrong and partly correct action’ responses). This adds to the remarks made in subsection 8.2.2.1 about group’s G correspondence to the lowest proportion of ‘correct’ responses. A strong tendency for ‘wrong and partly correct action’ responses was also identified in the case of questions from group D. When the children compared a story or a computer world with the real world, in one out of the four ‘action’ responses they provided, they did not define a ‘correct action’ (13% of ‘wrong and partly correct action’ responses out of 55% of ‘action’ responses in general). This was a surprise because it was expected to be easier for children to focus on what happens in one model and the real world instead of considering two different models at the same time, as is the case in all the other questions. When the children were asked to compare participants (group E) or rules (group F) they very rarely made comparisons in terms of 'action x' (2% and 5%, respectively) and they paid some attention to both 'actions 1' and 'action 2'. Although the children had access to the pictures of rules, they did not answer in terms of actions more often than in the other cases. In the case of comparing rules the children had the weakest tendency to consider actions in general (38%).

Although the children were not asked to focus on 'action 1' and/or 'action 2' – excluding the questions of group A and G – on the whole, 'action 1' more often attracted the children's attention either on its own or together with 'action 2'. From a WM perspective this is an encouraging result because it shows that actions where 'adjacent' is an issue are meaningful to children.

From Figures 8.7 and 8.8 below we can see that, in general, the tendency to focus on 'action 1' and/or 'action 2' varied across questions of the same group. In the cases where stories or computer worlds differed in terms of both 'action 1' and 'action 2', 'action 1' was more often identified as an element of comparison. These questions were about comparison of stories (the first three questions of group B) and comparison of a story to a computer world (the fourth, fifth, seventh and eighth questions of group C). That was also the case in the remaining questions, where stories and computer worlds were described by both actions, although the tendency for 'action 1' responses was closer to the tendency for 'action 2' ones.

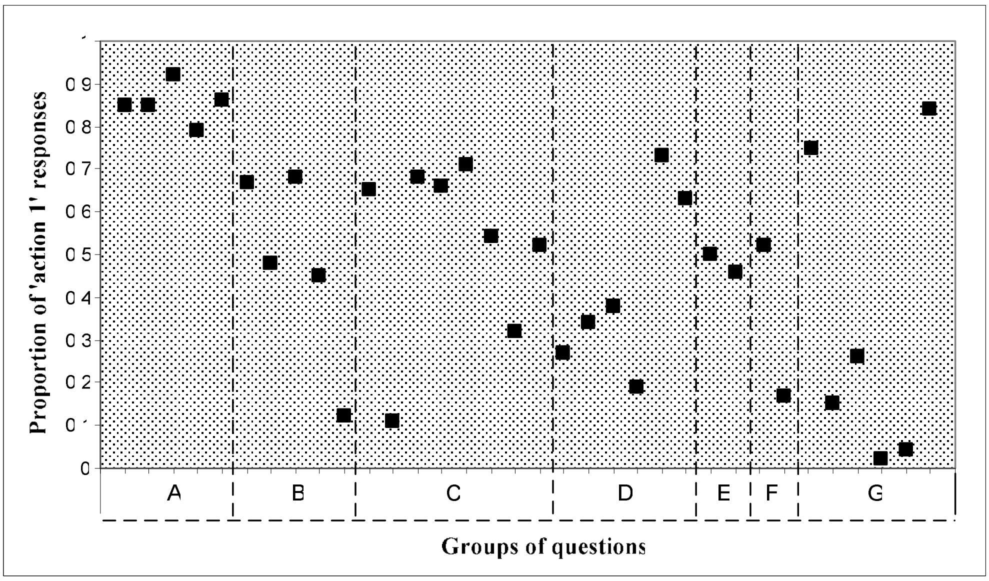


Figure 8.7 – Proportion of 'action 1' responses for each question

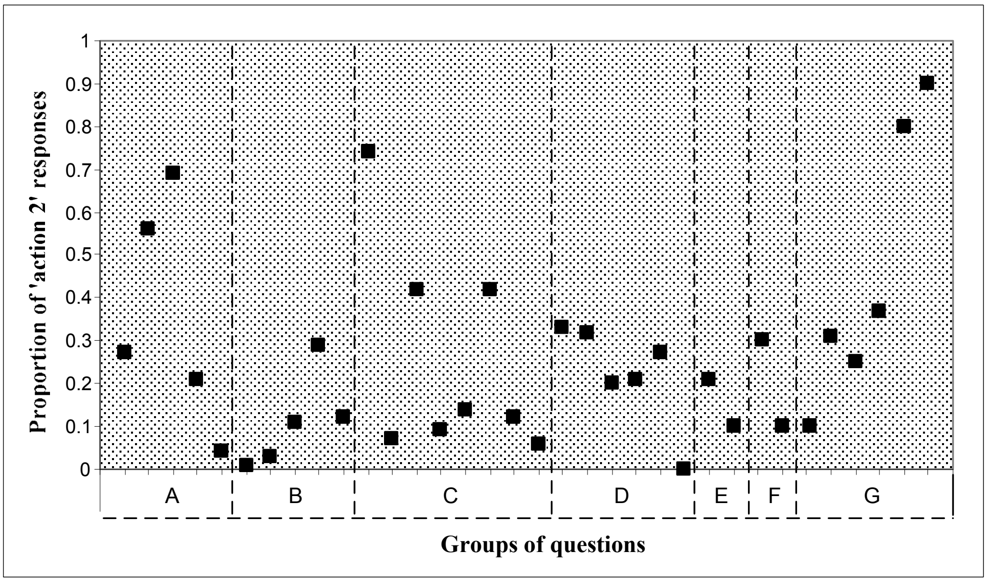


Figure 8.8 – Proportion of 'action 2' responses for each question

When the children were asked to respond to pairs of questions (one asking for similarities and the other for differences), they nearly always responded in the same way regardless of the action they considered. For instance, when they were asked to respond to the questions "*Is what happens in the story* (i.e. 'Cats') *like what happens in the computer world? How?*" and "*Are they different in any way?*" (the first two questions of group C) their tendency to provide 'action 1' responses was much stronger in the first case than in the second. That was also true for 'action 2'. The first of the above questions (included in the 'Cats' task) was related to the strongest tendency for 'action 1' and 'action 2' responses and to the lowest for 'correct' responses as was noted previously (see subsection 8.2.2.1). Furthermore, from Table 8.8 it can be seen that when the children were asked to compare a story to a computer world they had a strong tendency to reflect on both actions (26%). From Figures 8.7 and 8.8 we see that when the children were asked to focus on a computer world that run in order to describe it (the second and third questions of group A), to compare it with a story that had the same structure (the first, second, third and sixth questions of group C) and to compare it with the real world (the second, third and fourth questions of group D), then their tendency to consider 'action 1' did not differ considerably from their tendency for 'action 2'. Then, it might be the case that when the computer world runs it is easier for children to identify both actions included.

Overall, as might be expected, children's tendency to look at actions might be related to the question itself (if it asks children to focus on actions) and the way a model is presented (as a story or a computer world). Besides, regarding the actions involved, it was found that one possible reason that ‘action 1’ was more often noticed than ‘action 2’, was the fact that ‘action 1’ was presented first, thus it was more likely to be noticed. Then, if our intention is to draw children’s attention to structures, we should ask them to do so and probably we could involve more of computer models in which ‘conditional’ or ‘un-conditional’ changes might be included.

8.2.3.4 Summary of results about elaborated features

Overall, the degree of context dependency was remarkably limited. The issue of a situation or a computer model being ‘realistic’/‘unrealistic’ was a problem for the children but in a different sense it was not. On the whole, the children were able to think naturally about actions (conditional or not) seen as rules and to deal with the structure of rules. This task was harder when the children were dealing with an ‘unrealistic’ situation and with ‘abstract’ rules. The children did not often think of the conditions of the actions, but they tended to do so when the elements to be compared differed in terms of the conditions of the actions. They were also able to think about the kind and number of participants and about outcomes. Outcome and action were often seen as alternatives. The children seemed to make a choice between the two, thus when the tendency for ‘model outcome’ responses was high the tendency for ‘action’ ones was low and the reverse. In addition, it was very difficult for the children to define a common structure of different situations in terms of the correspondence between participants, even when they were pushed quite hard to do so.

8.2.4 Concluding remarks

The following statements give a broad picture of how the children managed across the different tasks and questions:

- The children were able to think about the relations between situations, computer models and the real world.

  When the children replied to the questions (descriptive, comparative and predictive) they nearly always provided a response. The great majority of their responses were ‘interpretable’, ‘valid’ and ‘justified’. Only a few of the ‘justified’ responses were ‘wrong’ or were ‘personal judgement’ responses. The level of correctness was generally quite high with a few exceptions. Thus, it seems that the questions concerning the relations between situations, computer models and the real world were manageable but also challenging for the children.

- The children could cope with the idea of modelling in the WM way.
  WM was designed to represent situations, which are similar at the abstract level of rules and models, but have different meanings. At the same time, WM offers certain modelling possibilities regarding the specific way situations are to be represented – in terms of actions and conditions of actions. In this study, the idea of a situation and a computer model was used to isolate limited features of a real situation and thus to facilitate children to focus on actions and conditions of actions. It was found that the children paid attention to the very basic fact of such an approach; the change of the nature of the participants in the situations or the computer models presented to them. There was generally a strong focus on actions and conditions, although actions were more often considered than were conditions. Conditions were mentioned, but the extent of this depended on what the children were asked. What is also encouraging for young children's modelling abilities is that they managed to identify common structures for a range of different things – the transformation of cats to dogs and the spreading of diseases and news. There was generally a weaker tendency to respond in terms of other modelling aspects such as the general structure of a model, the correspondence between the participants, the outcome of the model and the participants' kind, than there was to reply in terms of actions and conditions. On the whole, this way of thinking would be helpful to children if they were to carry out modelling activities.

- Patterns of responses were not very context dependent.
  The children had some difficulties when they responded to questions about a very 'unrealistic' situation. When familiar participants, such as cats and dogs, were behaving in a 'crazy' way the success rate was lower than in all the other cases. It was not easy for the children to make the necessary abstractions in order to be able to identify correctly the modelling aspects of the 'crazy' actions that the familiar participants perform. By contrast, when the children were dealing with situations where the participants were 'abstract' objects the level of success was higher. However, in general, the level of context dependence was very low

when the children were deciding on which modelling aspect of the situations presented to them they would focus on. This is very encouraging for WM as it might be the case that even quite young children are able to use its basic elements (actions and conditions of actions) to describe different situations in a 'uniform' way.

- The children's tendency to look for structures was related to the type of questions to which they responded.

  When the questions straightforwardly asked them to focus on action, by asking them to give an account or to comment on the possibility of a specific situation (groups A and G, respectively), the children did respond in terms of actions and conditions of actions. On the other hand, when the children were asked to focus on rather broader aspects which included different stories (presented verbally or pictorially) or computer worlds or on elements of them (their rules), the children had a considerably stronger tendency than before to give 'model outcome' and 'general structure' responses and a weaker tendency to give 'action' and 'condition' responses. Thus, when designing modelling activities with WM for young children, as it is not always the case that they look at actions and conditions – there are other 'attractive' aspects for them to consider such as the outcome of the model or the kind of the participants – children should be clearly asked to focus on specific changes.

- Across different questions of the same group, the children did not always have a similar tendency to answer in terms of a specific feature.

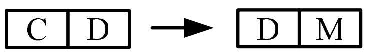
  For nearly all the modelling aspects of a response, there was some variation of the children's tendencies across the different questions of the same group. In the case where a group of questions included pairs of questions – one looking for similarities and the other for differences – then different patterns of responses were obtained for these two aspects. When the children focused on similarities, the pattern of responses was much more like the pattern of responses to the descriptive questions (more actions and conditions). By contrast, when reflecting on differences, the children shifted to the outcome of the model and the kind of the participants, even in the cases where this was not strictly appropriate.

8.3 Drawing rules

One of the a few cases when the children were required to deal with the specific way that WM rules are defined was when they responded to two questions asking them to draw the rules describing two stories – one about cats and the other about diseases. These questions were part of the ‘Cat/Disease’ task that was administered to the children during the last session, after they had spent some time defining their own rules during the learning tasks. I was trying to find out if children’s ability to consider a situation in terms of structures could be assessed through their performance in drawing WM rules. The rules the children had to draw were the same for both stories; the ‘Changes other object’ and the ‘Change’ rules.

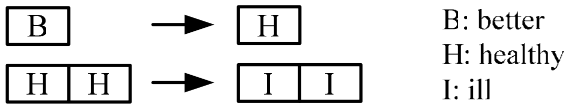
Quite often the children defined both rules correctly – 64% in the story about cats and 59% in the story about diseases. Surprisingly, the children’s performance in the story about cats was better than in the story about diseases, even though the responses to the questions included in the ‘Cats’ task corresponded to a lower level of correctness compared to the questions included in the ‘Diseases’ task. In both stories, the ‘changing by itself’ action was more often the one that was drawn correctly. The children gave nearly the same proportions of ‘correct’ responses and of specific kinds of actions and conditions of actions across the two stories (66% for the ‘changing an object’ action and 78% for the ‘changing by itself’ action). Thus the topic did not seem to be an important variable – that is, there was little context dependence.

A common mistake in both stories – around 12% of the total number of responses collected – was that both actions were incorporated in a single rule. Such a response was one like:



C: cat
D: dog
M: mouse

It seems that here the children pictured in the same rule two successive actions – a cat changing into a dog and the dog changing into a mouse. Other difficulties the children had were related to their confusion about the kind of changes (about 12% in both stories) and the condition that a change takes place (about 10%). For instance, in the case of diseases, some pictured a person that is ‘better’ changing to a ‘healthy’ one and someone who is ‘healthy’ changing to ‘ill’ when he meets a ‘healthy’ person. In the first case the action pictured and in the second the conditions for the specific action drawn were not included in the story presented to the children:



It should be mentioned that for drawing the rules, the children had to fill the empty boxes of the rules, thus they knew beforehand that they had to draw one rule that had a condition and one that did not.

On the whole, the children seemed to be able to identify the actions describing what was happening in the stories and then to present them in the form of pictures of rules. Besides, they seemed to be able to distinguish between actions that came about only if specific conditions were satisfied and those that did not. They could identify the requirement that participants had to be adjacent as one condition for the ‘changing an object’ action. They did not have any problem in using the ‘Changes other object’ rule to represent a change in one of the properties of an object. This was one of the difficulties the children had during the first main study (see subsection 6.3.1.2) when they were asked to draw a rule for representing the change of an ignorant person to an informed one when they meet. Different children participated in the two stages of the research. The sequence of the learning and research tasks in the second stage probably helped them to overcome this difficulty that might initially had. Alternatively their age might have played a role considering that the children participating in the second stage were older than those in the first one.

8.4 Writing your own story

When doing the ‘Cats’ task, the children had to respond to the question “*Can you write your own story that makes sense? For example, the cats could be caterpillars. What might the dogs and mice be?*”. Then, they were asked to write their own story without having to define it in terms of rules and one possible participant was suggested. The intention was to find out if children use ideas about the real world when creating their own stories that ‘make sense’ to them.

The stories children write might or might not have a real world interpretation. A ‘realistic’ story is one like “1. A cat is meeting a dog and it gets eaten by the dog.

The cat becomes part of the dog. 2. The dog dies because the cat was poisoned. 3. The mice eat the remains of the dog and the dog becomes part of the mice" or like "There was a cocoon, the cocoon changes into a caterpillar and the caterpillar changes into a butterfly". On the contrary, stories like "First there's an egg. When one egg touches another it turns to a tadpole. The tadpole touches another tadpole and turns to a frog", have no real world interpretation.

The participants in children's stories might come from the 'Cats' story given to them or they might be new. Besides, children might use one participant (i.e. caterpillar) suggested by the question itself. For example, in a story like "In this world, caterpillars are eaten by birds and birds are eaten by men", the children involved three different participants, one was given by the task (caterpillar) and the other two (birds and men) were invented by them.

Regarding the kind of actions included, children might use one of the actions included in the 'Cats' story ('changing an object' and/or 'changing by itself') or they might think of a new one. For instance, a story like "A seed, then turns into a root then turns into a flower", is a 'realistic' one. The participants in the story, which were invented by the children, perform the same kind of action – an object is changed by itself to a different object.

8.4.1 Analysis of results

All the children wrote their own stories (only 1% did not respond) and nearly all the stories were 'interpretable' (94%). The stories will be discussed by answering the following questions:

- Did the children's stories have a real world interpretation?
  The children did not seem to have a strong preference either for real world stories (56%) or for 'unrealistic' ones (44%).

- What are the participants in the children's stories?
  In nearly all of the stories (86%), one or more of the participants involved was invented by the children, in the sense that it was not one used in the 'Cats' story (cats, dogs and mice) and not the one suggested by the question itself (caterpillar). The caterpillar was used in half of the cases (50%), while the participants used in 'Cats' appeared much less often (18%). Furthermore,

equal proportions of the children included one or more than one participant in their stories. When more than one kind of participant were involved (50%), the most favoured group consisted of the caterpillar and one or more participants invented by the children (79%).

- What kinds of actions did the participants perform in the children's stories?
  In the children's stories, one of the actions performed by the participants was nearly always 'action 2' – an object changes by itself to a different object – (84%), less often was 'action 1' – an object meets another object and changes into it – (33%) and even less often was 'action x' – an action invented by the children (14%). When 'action 2' was included, then most often, no other kind of action was incorporated into the story (63%). This was also the case for 'action x' (67%). On the contrary, when performing 'action 1', the participants most often performed one more kind of action ('action 2' or 'action x') (78%). On the whole, the children more often wrote stories where only one kind of action was included rather than stories including more than one kind of action (69% as opposed to 29%). When considering those containing more than one kind of action, the most favoured group of actions consisted of 'action 1' and 'action 2' – a combination that was used in 'Cats'.

We can also ask about correlations between the above choices. In the case where the children wrote a story, that had a real world interpretation (61 stories), by far the largest category was when the participants performed only 'action 2' (49 stories). In all these 49 cases, the children used only invented participants or the given one (i.e. caterpillar); they did not involve any participant from 'Cats'. By comparison, in the stories, that had no real world interpretation (47 stories), a large category of responses was that in which the participants performed both 'action 1' and 'action 2' (27 stories). However, as above, most of them did not use any participants from 'Cats'. Although the level of connection between the 'Cats' story and the stories written by the children was low, when the children could imitate it, they were willing to do so.

Sometimes a child gave two or more stories. 28 out of the 112 stories provided by the children were given in twos or in threes. The great majority of these 28 stories (78%)

were groups of stories which all had a real world interpretation, the same kind of action ('action 2') was described, but the participants were different. In this case, the children took the initiative and used the same abstract structure ('action 2') to represent different situations – something we would have liked them to do when they responded to the group A, B, C, D, E and F questions.

8.4.2 Summary of results

The children were implicitly asked to write a story having a real world interpretation ('making sense'). For that reason, the potential participant introduced was a real world creature, the caterpillar.

The children were however just as willing to write 'fantasy' stories as 'real world' ones. In both cases, they were innovative regarding the participants, but they had a different tendency to choose specific actions. In the stories that had a real world interpretation, the action 'changing by itself' was more often used. The children tended to talk about changes they knew about from their everyday life, like "Pupa became caterpillars and then became butterflies" or "A spawn could turn into a tadpole, moving into a frog". The 'fantasy' stories were more often about both of the actions that had been previously presented to the children in the 'Cats' task, 'changing an object' and 'changing by itself'. The children could use this pair of actions to make a 'realistic' story, if the actions were about changes of the properties of the objects instead of their nature. But they were not willing to do so. Thus we might expect children to have difficulties in working on the research tasks to follow on actions where such kinds of changes take place (e.g. a healthy person is changed to an ill person by contact with an ill person and then an ill person changes to someone who is better). However, it was found that the children did not have this difficulty; thus probably the claim that was made before (see section 8.3) about the effectiveness of the learning and research tasks becomes stronger.

8.5 The modelling questionnaire

The modelling questionnaire was the final task administered to the children during the last session after they had spent a substantial time with the WM learning tasks. Two important aspects of the modelling process at the school level were under investigation:

i. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful?

ii. Can children create a WM model using WM objects and rules?

8.5.1 Understanding a WorldMaker model

In order to explore the children's understanding of WM models, four problematic modelling scenarios were presented to them. In each scenario several statements expressing alternative ways of thinking about models, were provided. The children had to agree or not with each statement.

8.5.1.1 Organising the analysis of the children's responses

The presentation of the children's responses to the first four scenarios of the modelling questionnaire is carried out in two successive stages. Firstly, a picture of the quality of data collected is provided, by answering the following questions:

- Did the children declare their preference for the statements related to each problematic modelling scenario?
- Did they express their preference in an interpretable way?

This having been done, a picture of the kind of data gathered is given by responding to the question:

- Did the children agree or disagree (partly/strongly) with each statement?

The data related to the question above is then used to answer a different question:

- Did the children's choices form patterns? Amongst statements for a given scenario were the choices consistent? Across different scenarios were the claims similar or not?

However, before the presentation of the analysis, I should make explicit the way that the children's choices were treated for the above questions to be answered. When the children made a single choice ('strongly agree' (SA), or 'partly agree' (PA), or 'partly disagree' (PD), or 'strongly disagree' (SD)) then their position on the specific statement was clear. But sometimes, the children made double, triple or quadruple choices. Table 8.9 below depicts the way that responses of the above kinds were interpreted and the rationale for the interpretation.

Choice	Interpretation	Rationale
SA – PA SD – PD	PA PD	Children respectively agree/disagree with a statement but having some hesitations and doubts
SA – PD SD – PA	PA PD	(As above)
PA – PD	Randomly assigned to PA and PD choices	Children agree and disagree with a statement having some hesitations and doubts
SA – SD	Omitted	Children take two contradictory positions against a statement
Three choices	Omitted	Children's choices cannot be interpreted
Four choices	Omitted	Children have not decided on the issue under consideration

Table 8.9 – Interpretation of the children's responses to the modelling questionnaire

Overall, in responding to the questionnaire, the children had a very high rate of making responses and of responses that were 'interpretable'. In all questions but one, the response rate was over 90% and of these never fewer than 98% were 'interpretable'.

8.5.1.2 Presenting the children's responses

First problematic modelling scenario

"*Natasha has made a diseases 'world', with a few rules. But when she runs it, no one in her 'world' gets ill.*
What might be wrong?
1. *All her rules must be wrong.*
2. *One of her rules must be wrong.*
3. *A rule is missing.*"

As shown in Figure 8.9, concerning this scenario, the children tended to agree with the last two statements (76% and 80%, respectively), which were those amongst the three statements that could be thought of as the most acceptable. By contrast, the children were almost equally divided on the first statement that was intended to be the least acceptable response.

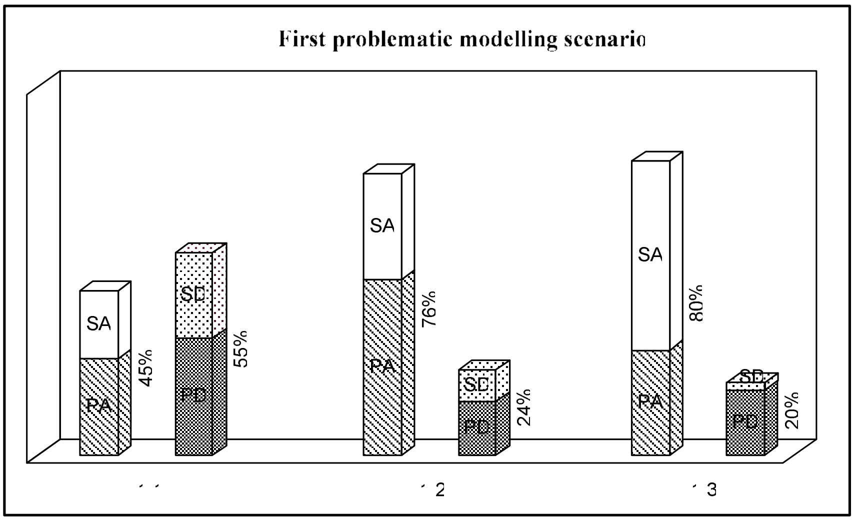


Figure 8.9 – Proportions of the children's responses to the first scenario of the modelling questionnaire

Given that the children responded to all three statements, the 'best' pattern of responses would be to disagree with the first statement, and to agree with the second and the third. In fact, as is shown in Table 8.10, 42% responded in this way. Taking patterns that were nearly as acceptable (disagreeing with one of the last two statements, but agreeing with the other and rejecting the first), a further 15.3% of responses were added. Thus 57% gave acceptable patterns of responses. However a further 17% chose to agree with all statements, leaving only a minority (2%) giving the least favoured pattern.

Pattern of choices[1]	Frequency	Rate
DAA	41	41.8%
DAD	5	5.1%
DDA	10	10.2%
AAA	17	17.4%
AAD	12	12.3%
ADA	11	11.2%
ADD	2	2%

Table 8.10 – Patterns of the children's responses to the first scenario of the modelling questionnaire

[1] Codes show disagreement (D) or agreement (A) with the statements, in the sequence statements were given – for instance, DAA shows disagreement with the first statement and agreement with the other two (second and third)

Second problematic modelling scenario

"*Natasha goes on trying to get people in her 'world' to become ill. She wonders whether adding more rules might get this to happen.*
What should she do?
1. *She may need to add a rule.*
2. *She may need to change a rule.*
3. *She should work out why people were not getting ill, before doing anything.*"

Dealing with the second problematic modelling scenario, the children tended to agree with all the statements suggesting possible corrective actions for the unsuccessful computer model. Figure 8.10 shows that a large majority of the children – as might be hoped – favoured the last statement (84%).

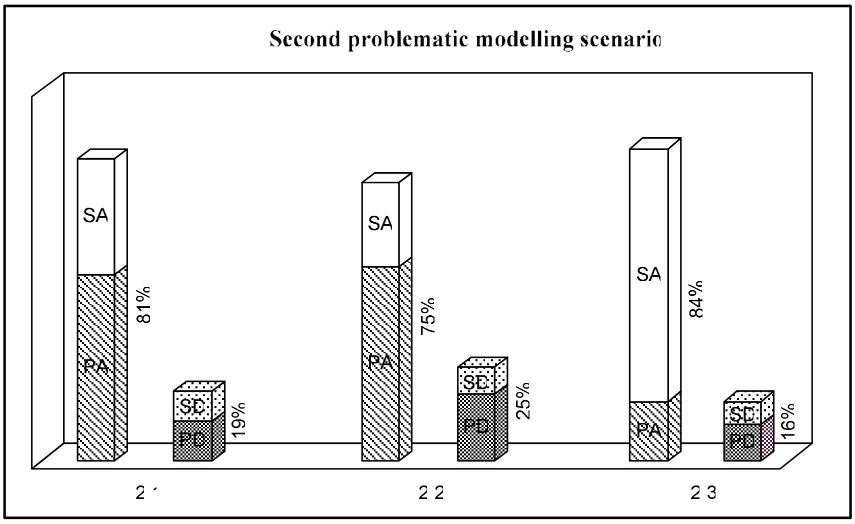


Figure 8.10 – Proportions of the children's responses to the second scenario of the modelling questionnaire

The largest group of children were those who agreed with everything (52%), which is perfectly reasonable (see Table 8.11). Very few children disagreed with the last statement (17%) and a total of 82% agreed with at least two statements, one of which was the last.

Pattern of choices	Frequency	Rate
AAA	49	51.6%
DAA	16	16.8%
ADA	13	13.7%
DDA	1	1.1%
ADD	4	4.2%

Pattern of choices	Frequency	Rate
DAD	1	1.1%
AAD	10	10.5%
DDD	1	1%

Table 8.11 – Patterns of the children's responses to the second scenario of the modelling questionnaire

First and second scenarios

The two problematic modelling scenarios were related, and some responses to the different scenarios were parallel. It is therefore useful to see if the children gave 'similar' answers to the two scenarios.

Figures 8.9 and 8.10 show that the children expressed an almost identical preference for statements 1.2 – "*One of the rules must be wrong*" – and 2.2 – "*She may need to change a rule*" – (around 75% agree with each), and for statements 1.3 – "*A rule is missing*" – and 2.1 – "*She may need to add a rule*" – (about 80% agree with each). Table 8.12 below makes this comparison more specific.

Choice	Statements 1.2 & 2.2		Statements 1.3 & 2.1	
	Frequency	Rate	Frequency	Rate
SA	14	14.3%	20	20.2%
PA	57	58.2%	62	62.6%
PD	21	21.4%	11	11.1%
SD	0	0	0	0
SA – SD	6	6.1%	6	6.1%

Table 8.12 – Proportions of the children's responses to related statements of the first and second scenarios

According to Table 8.12, only a very small minority made contradictory choices about these pairs of statements. Thus, only 6% strongly agreed with one statement and strongly disagreed with the other. For both pairs of related statements (statements 1.2, 2.2 and statements 1.3, 2.1), the great majority (94%) when agreeing with one agreed with the other as well. In other words, they were consistent, in that if they chose a cause for the unsuccessful attempt to build a computer model, then they next chose an action that deals with that cause. The children might have chosen one of the pairs ((1.2,2.2) or (1.3,2.1)) to favour – seeing the consistent patterns they represent as alternatives. However, as seen in Table 8.13 below, they did not do so. A good majority (SA and PA responses were 76%) were willing to agree (partly or strongly) with both pairs (i.e. all four statements).

Statements 1.2, 2.2 & 1.3, 2.1

Choice	Frequency	Rate
SA	1	1.1%
PA	71	74.7%
PD	12	12.6%
SD	0	0
Three choices	11	11.6%

Table 8.13 – Proportions of the children's responses to all related pairs of statements of the first and second scenarios

Third and fourth problematic modelling scenarios

To facilitate comparison, the third and fourth scenarios – which were closely related – are analysed together. Both contrasted opinions that were based on the meaning of a model with ones which were based on the rule conditions. These juxtapositions were intended to find out if the children considered the modelling process from a 'semantic' perspective as opposed to a 'formal' one.

The third problematic modelling scenario was as follows:

> "*Peter makes a 'world' about rabbits. He wants the screen to fill up with rabbits starting with a few rabbits and foxes. He is pleased because this is what happens.*
> *Gill objects: "Your 'world' is no good. It has a rule where rabbits eat foxes, and that doesn't make sense. It could not happen."*
> *Peter: "That doesn't matter. My 'world' is all right because it gives the result I want."*
> *What do you think?*
> 1. *Do you agree with Peter?*
> 2. *Do you agree with Gill?*
> 3. *A 'world' which does what you want is all you need.*
> 4. *It is more important to get rules which make sense than to get the 'world' to do what you want.*"

The fourth problematic scenario was as follows:

"*Ann makes a crazy 'world' about boats and sharks. She expects the shark to 'give birth' to boats! She is worried because that doesn't happen.*
Parvin says: "Your 'world' doesn't make sense. It can't happen. That's why it doesn't work."
Ann objects: "No. My 'world' doesn't work because I've got the rule wrong."

What do you think?

1. *Do you agree with Parvin?*
2. *Do you agree with Ann?*
3. *A 'world' which does what you want is all you need.*
4. *A 'world' which makes sense is all you need.*
5. *If you want to get the 'world' to do what you want, you should get the rules right, regardless of whether they make sense or not.*"

In both scenarios, as Figures 8.11 and 8.12 show, the children had a slightly stronger tendency to consider the modelling process from a 'semantic' rather than a 'formal' perspective. Slightly more often, they preferred rules and computer models that made sense than rules and computer models that were effective.

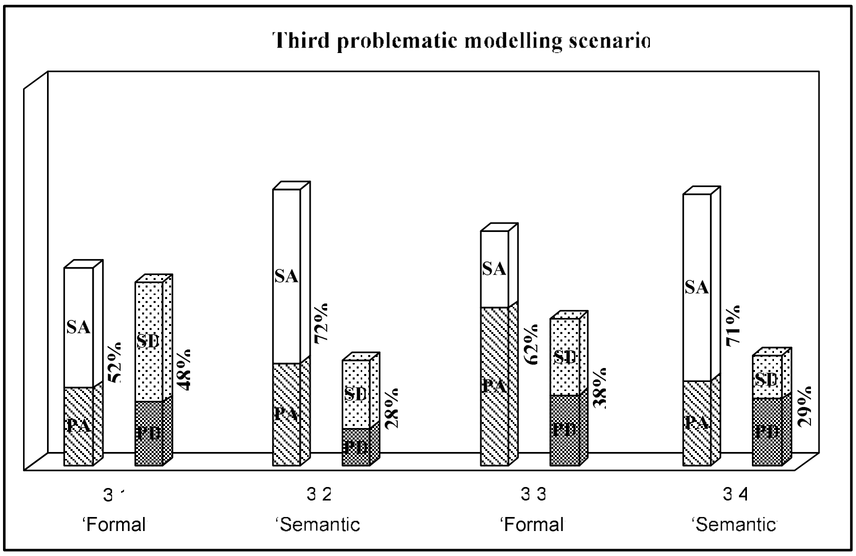


Figure 8.11 – Proportions of the children's responses to the third scenario of the modelling questionnaire

Thus, in the third scenario, more children agreed than disagreed with Gill (3.2) and with the statement "*It is more important to get rules which make sense than to get the 'world' to do what you want*" (3.4). In the fourth scenario, for the first four questions the 'semantic' statements were more often accepted than the 'formal' ones. However, the most popular single choice was the 'formal' statement "*If you want to get the 'world' to do what you want, you should get the rules right, regardless of whether they make sense or not*" (79% of agreement).

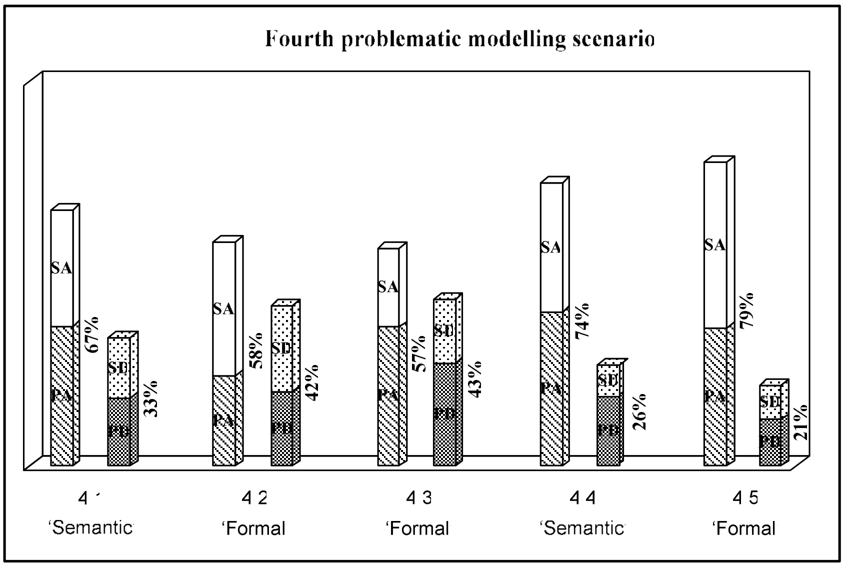


Figure 8.12 – Proportions of the children's responses to the fourth scenario of the modelling questionnaire

In both scenarios, although each individual question forced a choice between 'formal' and 'semantic', more than half of the children agreed with each statement regardless of whether it was a 'semantic' or a 'formal' one.

We could also ask whether each individual child gave 'semantic' biased or 'formally' biased responses. Given that the children responded to all the statements of the third scenario, then if they had a 'semantic' view, they made choices like DADA, that is, disagreement with Peter (3.1), agreement with Gill (3.2), disagreement with the statement "*A 'world' which does what you want is all you need*" (3.3) and agreement with the idea that "*It is more important to get rules which make sense that to get the 'world' to do what you want*" (3.4). A child who was a 'formalist' would have a profile like ADAD. Table 8.14 below shows that 49% of the children had a profile that was close to the 'semantic' one and 27% a profile close to the 'formal' one.

	Choice	Frequency	Rate	Total
	ADAD	15	15.2%	
	AAAD	7	7.1%	
'Formal'	ADDD	1	1%	27.3%
	ADAA	4	4%	
'Semantic'	DADA	25	25.3%	48.5%
	AADA	3	3%	

	Choice	Frequency	Rate	Total
	DAAA	19	19.2%	
	DADD	1	1%	
	ADDA	6	6.1%	
	DAAD	4	4%	
'Mixture'	AAAA	10	10.1%	24.2%
	AADD	3	3%	
	DDAA	1	1%	

Table 8.14 – Patterns of the children's responses to the third scenario of the modelling questionnaire

Regarding the fourth scenario, as Table 8.15 shows, most children favoured a mixture of 'formal' and 'semantic' statements (52%). Concerning the rest of the children, slightly more were close to the 'formal' profile than the 'semantic' one (27% and 21%, respectively) – reverse in the third scenario where the children made as well much more of clear choices. A child having a 'semantic' profile would agree with Parvin (4.1), disagree with Ann (4.2) and with the statement "*A 'world' which does what you want is all you need*" (4.3), agree with the statement "*A 'world' which makes sense is all you need*" (4.4) and disagree with the idea that "*If you want to get the 'world' to do what you want, you should get the rules right, regardless of whether they make sense or not*" (4.5). The profile of a 'formalist' child would be like DAADA.

	Choice	Frequency	Rate	Total
'Formal'	DAADA	10	11.6%	26.7%
	DAAAA	13	15.1%	
	ADDAD	1	1.2%	
'Semantic'	AADAD	5	5.8%	20.9%
	ADDAA	10	11.6%	
	ADAAD	2	2.3%	
'Mixture'	ADDDA	3	3.5%	52,4%
	ADAAA	13	15.1%	
	DADAA	1	1.2%	
	DDADD	1	1.2%	
	ADADA	4	4.6%	

Choice	Frequency	Rate	Total
DADDD	3	3.5%	
AAAAA	8	9.3%	
AADDD	1	1.2%	
DDAAA	1	1.2%	
DADAD	1	1.2%	
AADAA	8	9.3%	
AAAAD	1	1.2%	

Table 8.15 – Patterns of the children's responses to the fourth scenario of the modelling questionnaire

Thus, in the fourth scenario, the children were not generally willing to make a choice between rules being effective and rules making sense. The most common profile of a child being neither 'formalist' nor 'semantic' would be ADAAA (15%) where it has agreed with everything except Ann's 'formalist' view. In the third scenario, the children seemed to make the choice, slightly preferring the 'semantic' to the 'formal' position.

To investigate consistency between responses to different scenarios was a statement, which was the same in both third and fourth scenarios. This statement reflected the 'formal' view that "*A 'world' which does what you want is all you need*". As is shown in Table 8.16, most of the children (75%) had a consistent view about that statement. A majority, but only a very small one, was in favour in both cases, with 45% giving the same positive response on both occasions and 30% the same negative response.

Statements 3.3 & 4.3

	Choice	Frequency	Rate	
Consistent	**AA**	43	44.8%	75%
	DD	29	30.2%	
Inconsistent	**DA**	13	13.5%	25%
	AD	11	11.5%	

Table 8.16 – Proportions of the children's responses to related statements of the third and fourth scenarios

8.5.1.3 Summary of results

In general, the children were willing to declare their preference amongst quite general statements investigating the way they see the relation between computer models, rules and the real world and they expressed their preference in an interpretable way.

When the children dealt with a real life situation, they seemed able not only to identify the causes of an unsuccessful computer representation but also to choose actions that deal with these causes. Reflecting on a ‘crazy’ computer model, even though the issue of rules and computer models which ‘made sense’ and the issue of rules and computer models which were effective, looked almost equally attractive to the children, when they decided to choose one, then those having a ‘semantic’ profile were chosen slightly more often than those having a ‘formal’ profile.

By design, the children were offered choices about how to think about a computer model and what to do with it if it fails. It was clear that they were more likely to agree with several options than to pick just one. The questionnaire also picked up the issue of the ‘formal’/‘semantic’ balance we saw before (see Chapter 6) when the children had to decide about ‘possible’ and ‘impossible’ rules and were roughly equally divided between those invoking what a computer can or cannot do and those considering what can or cannot happen in reality. In such matters, then, the children were rather eclectic in their views. If we consider their age and the experience they had of modelling, this could well be seen as a good thing. The children mostly tended to give the responses we would prefer: in particular those stating that one should think about things before choosing what to do.

8.5.2 Creating a WorldMaker model

For the last question of the modelling questionnaire, the children were presented with the following situation:

> “*Mary and Abdul are making a ‘world’ which shows a forest fire spreading and burning down a whole forest. They think of some objects which might be useful. Which of the objects underneath which they thought of might be useful for making this ‘world’?*”

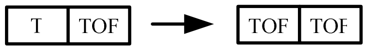
The children had to make choices amongst the following ‘objects’: ‘a tree’, ‘whole forest’, ‘a tree on fire’, ‘fire spreading’, ‘a burnt tree’ and ‘burnt forest’. Then, they had to define one WM rule for a forest fire computer model. By design, the list of possible ‘objects’ included inappropriate ones (‘whole forest’, ‘fire spreading’, ‘burnt forest’) as well as ones well suited to making a WM model.

8.5.2.1 Presenting the children’s WorldMaker models

Nearly all of the children (94%) made a decision about the kind of objects involved in a forest fire computer model. Most often more than one and fewer than six ‘objects’ were selected (82% of responses), thus the children chose more ‘objects’ than the maximum number needed for a WM rule, which is four. One out of four responses included ‘whole forest’, ‘a tree on fire’, ‘fire spreading’ and ‘burnt forest’. Quite often (70%) the children selected ‘fire spreading’. Looking at the justifications that the children provided for the choices they made, most often (in 87% of their responses) their decision was taken on the basis of what is involved in a forest fire. Such a response was one like “You need a whole forest so you can light it on fire. You need a tree on fire to start a fire. You need a fire spreading so it gets everywhere. You need a burnt forest because that’s what it ends up as”.

When the children had to define their own rule for the forest fire computer model, nearly all were willing to do so (90%) and most of their responses were accounts of reasonable actions (85%). As might be expected, they nearly always used all or some of the ‘objects’ they had previously selected as being useful for a forest fire computer model. The great majority (83%) described a forest fire in terms of what happened to the forest providing a global picture of the fire. Such a response was one like “The whole forest comes across a tree on fire. The tree on fire makes another tree on fire. It has started to spread” or like “The whole forest becomes on fire and the fire is spreading. Then, it shows the burnt forest”. A minority provided responses like “Tree next to tree on fire, burnt tree”. This tendency for a global picture of a forest fire might have been induced by the terms in which the task was posed, asking about a model of ‘a forest fire spreading and burning down a whole forest’.

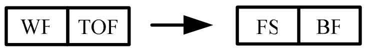
Although the children were able to give a reasonable account of the actions involved in a forest fire they were less successful in drawing the rules representing those actions. Only some children (20%) provided really adequate responses. One of them is the following: “This rule shows that a tree catches fire and it spreads” for the rule:



T: a tree
TOF: a tree on fire

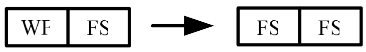
It appears that the children had difficulties in using the WM formalism to represent the ‘spreading’ action, even though in the previous research tasks (‘Diseases’, ‘News’ and ‘Disease/Rumour’) they worked on the spreading of diseases and news. The main problems the children had were the following:

i. They used the inappropriate ‘action-type’ object ‘fire spreading’ to define the ‘spreading’ action. Such a quite common response was one like:



WF: whole forest
TOF: a tree on fire
FS: fire spreading
BF: burnt forest

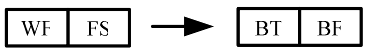
“Whole forest, then a tree on fire. The fire is spreading, then a burnt forest”. A case where ‘fire spreading’ was used to represent the object ‘fire’ is the following:



WF: whole forest
FS: fire spreading

“The fire starts off in the forest and spreads to make a big forest fire”.

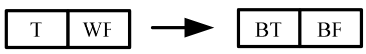
ii. The two cells in the ‘after’ picture of a rule were not necessarily the same as those in the ‘before’ picture. This is the case in the following response:



WF: whole forest
FS: fire spreading
BT: a burnt tree
BF: burnt forest

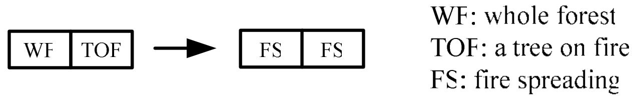
“This rule is showing a whole forest, a fire spreading, a burnt tree and then a burnt forest”.

iii. The appearance of new objects in the ‘after’ picture of a rule, was not justified in terms of the interactions between the objects in the ‘before’ picture, as needs to be the case in WM. An example of such a response is one like:



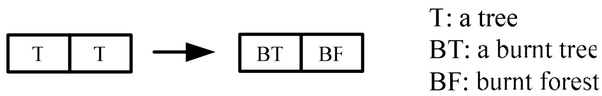
T: a tree
WF: whole forest
BT: a burnt tree
BF: burnt forest

"It shows a tree and a whole forest and it shows a burnt tree and a burnt forest". In this case, the children did not explain why 'a tree' changed to 'a burnt tree' and a 'whole forest' to a 'burnt forest'. In a very few cases, one of the 'before' objects was mentioned as the cause for the actions, as in the following response:



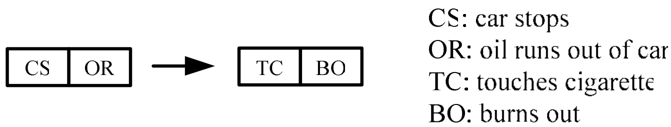
"The rule shows a whole forest which meets a tree on fire, and the fire starts spreading".

iv. The children did not use the form of a rule to represent a change of the objects – in terms of their nature or their position – that took place during the spreading of a fire. On the contrary, they mainly seemed to use it as a 'frame' in which they put different snapshots of a forest fire. This is the case in the following response:



"Firstly a tree, then a burnt tree and then finally a burnt forest".

Finally, the children were asked to think of any other objects or rules they wished. Only some children (27%) had time to do so as this was the last question of the last research session. Nearly all tried to picture other cases of fire in a forest or at home, and in doing so they had the same problems as discussed above. An interesting case is the use in rules of actions instead of objects, for example:



8.5.2.2 Summary of results

On the whole, the children were less successful in defining their own WM rules than in all the other research tasks. Although they gave reasonable accounts of what might happen during a forest fire, they had difficulties in drawing a rule to make a WM model of the event.

The task does, by design, suggest inappropriate 'objects' to see if children can discriminate them from more appropriate objects. The children's majority did not do so (only about a fifth succeeded completely).

It was also common for the children to try to picture in a single rule all the changes taking place in a forest fire – how the fire starts from a single tree and how a whole forest ends up burnt.

It might well be that if the task had offered fewer and more appropriate choices of objects and had given more direction as to which actions to picture, the children would have been more successful. But in this case we would not have learned, as we have here, the limits on how well they had understood and appropriated the conceptual framework in which WM models operate. It seems clear that the time they had spent dealing with the WM formalism during the research was not enough to get them to this point and so prevent them from making the types of mistakes mentioned above.

8.6 Overall conclusions

This study was looking for children's ability to think of situations in terms of structures as well as their understanding about the relationship between models and reality. It was found that when the children carried out descriptive and comparative tasks, they were able to focus on the basic elements of a 'structural' approach, actions and conditions of actions. This ability did not seem to be context dependent but it was more related to the type of questions to which the children responded – although across different questions of the same type, the children did not always look at structures in the same way. Regarding the specific way that abstract structures are defined in WM, the children were more successful in identifying actions and conditions of actions as the main elements of a situation than drawing them in a rule, especially in the case where they had to decide about the kind of objects and actions to involve.

As far as the relationship between models and reality is concerned, the children could see both an 'unrealistic' situation and a 'realistic' situation as plausible to be modelled. But, they were more successful in identifying correctly the modelling aspects (such as actions and conditions of actions) of a 'realistic' situation than of a ‘unrealistic’ one. Presented with an unsuccessful computer model, the children were able not only to identify the causes but also to suggest possible actions to deal with these causes, regardless of the kind of situation modelled – ‘realistic’ or ‘unrealistic’.

On the whole, this study shows that children of this age have the potential to use WM in order to express and explore their ideas about how different situations take place by considering the same set of rules.

CHAPTER 9

Discussion and Conclusions

9.1 Introduction

This final chapter attempts to synthesize the different stages of the research, bringing together all the research questions and research findings. Firstly, the main findings regarding all the specific questions for each stage are presented. Then the three general research questions as well as the children's performance across the different modelling activities are discussed, putting together material from each research stage. Where possible, my research findings are placed in the context of other research work. Afterwards, some advice based on this research is given to teachers wishing to use WorldMaker (WM) at school. The thesis closes with a short account of what was found out during the conduct of the research as well as by pointing out some of the limitations of the research findings.

9.2 The research as a whole

This research took place in three different stages – a small-scale preliminary study and two main studies involving a larger number of children. Although there was no early conception of the whole research and its design was a step-by-step process, a main idea operates in the entire research, that there is a unique aspect of children's thinking that children apply when dealing with the modelling process. Thus, this research intends to say something about the way that children think during a modelling activity, an issue that is very much related to the kind of modelling tool used, in our case WM. Consequently, as mentioned in Chapter 3, the main corpus of the research – explored in the first and the second main studies – was formed by the subsequent general research questions:

a. Can children understand, use and think about models in a WM form?
b. Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules?
c. How do children see the relation between models and the real world?

The research tasks used to explore the above issues require children to approach the following aspects of the modelling process:

i. Creation of a model;

ii. Description and explanation of a model's formal behaviour;

iii. Interpretation of the meaning of a model; and

iv. Exploration of a model.

The children participating in the first two stages of the research (the preliminary and the first main studies), were drawn from the last years of primary education; in the second main study they were in the first years of secondary education (this change was not by choice of the researcher, but because of availability).

The modelling tool used – WM – was expected to allow quite young children to deal with the modelling process, working on pre-defined models and creating their own. In the end, although this research focused on children's thinking when carrying out any modelling activity, the modelling tool used was not overlooked. An evaluation of the tool is inevitable, and then some guidelines might be given regarding the better design and use of modelling tools for young children.

9.3 Answering the research questions for each study

Each study aimed to answer a number of specific research questions. These questions, together with the research findings, are presented in this section. For each research question of the first and the second main study – which make up the main corpus of my research – cross references are provided to indicate the specific parts of the analysis (Chapters 6 and 8) from which the corresponding findings are drawn.

9.3.1 Preliminary study

As at the time of the research WM had never been used before in a systematic way, the preliminary study aimed to evaluate the WM interface and to look at children's understanding of how WM works. The research questions and the respective research data (see Chapter 4) are presented next.

- *Are children able to use WM? (PS-RQ-a)*

It was found that primary school children were able to use WM. They were able to get familiar with the basic features of WM within about half an hour, when dealing with specific tasks.

- *Are all of the tools recognisable?*

On the whole, the children learnt to distinguish the pictorial representations of the different tools used to stop and run a computer model, to plot and remove one or more fillers or to give them directions. The most successful tools were those that were iconically represented. Tools that are represented by more abstract, less iconic symbols were less successful. A tool was easily recognisable if the object that it represents functioned in the same way in real life (e.g. a pencil for drawing an object). Consequently, when designing a computer program for young children, a designer should know beforehand the range of the everyday objects that children of this age are familiar with. It can happen that a computer program offers a wide range of tools but children are not so keen to use them because either the procedures they represent are not known to children or the pictures of the tools are not familiar to them.

- *Do children think easily in terms of fillers (i.e. objects or backgrounds) and events?*

When the children engaged with the modelling process using WM, they were able to see an event in terms of the objects involved and the kind of actions they perform. They had no difficulty in appreciating that a background can be thought of as representing a ‘place’ in or on which an object ‘sits’, and that objects are to be thought about as localised. They were also able to provide successful examples of each kind of filler. When thinking about a computer model, they found it easy to identify objects that were needed, and were concerned about how best to represent them pictorially. Regarding events, the children were often able to consider a computer model in terms of the actions included in it. However, they had difficulty in going beyond thinking about one action at a time, finding it harder to think about a sequence of actions.

- *Can children understand and define rules?*

The children easily grasped the idea that rules describe the actions included in a computer model. But, it was difficult for them to accept the fact that ‘unrealistic’ events could be included in a computer model. This was also the case when they had to read rules and try to put them in a real world context. When they were asked to define a rule, they felt more comfortable in using ones previously presented to them. Usually, when they had to define a rule they avoided selecting it from the list of rules provided by WM. Cherry *et al.* (1999) also identified this tendency when using AgentSheets with 4th and 5th graders to create and explore models. In addition, in the case of WM there were some actions that they thought of as not needing to be defined by rules, since the objects were expected to have those actions ‘by their very nature’. For instance, the ‘movement’ action was thought of as being intrinsic to the objects, thus they saw no need to define the rule for it. This tendency was also identified during the second main study. In the ‘ABC’ task (see subsection 7.4.6), although no ‘Jump’ rule was included, no child pointed it out; it seems that they took for granted that the participants (objects A, B and C) would be able to move ‘by their very nature’.

- *Can children work on the probability of a rule?*

The children were able to accept the fact that the probability of a rule determines the behaviours of the fillers (i.e. objects or backgrounds). Interestingly, it was when they were dealing with the probabilities (settings) of the rules that they most often gave explanations coming from the computer model. On the whole, by following trial and error procedures they managed to work on the probability of a rule. But, they had difficulties in grasping the effect of changing the probability of more than one rule at a time.

- *What might be the nature of the tasks and situations that children can use? (PS-RQ-b)*

The children could cope with descriptive, explanatory, interpretative and exploratory questions as far as computer models were concerned. The creation of a computer model was the hardest task they had to accomplish. On the subject of the nature of the situation to be modelled, it was found that the children were concerned about the accuracy of the representation regarding a ‘realistic’ situation. In addition, familiar situations were easier for the children to handle especially in the case where less abstract thinking was involved.

9.3.2 First main study

In the preliminary study, it was found that simple modelling tasks were feasible for children even at this young age, so the first main study focused on an important and specific aspect of the modelling process using WM, namely their understanding and use of the idea of representing actions by rules in WM form. The specific research questions elaborated in this study (see Chapter 5) alongside the research findings (see Chapter 6) are given below.

- *Can children be effectively introduced to WM by playing a board game? (FMS-RQ-a, pages 100-105)*

Without having yet seen WM, the children were introduced to WM-style rules in the context of a board game. After playing the game according to a set of rules, they managed to suggest substitutes for the different objects in the rules and to define their own rules using the WM syntax.

- *Can children read WM rules? (FMS-RQ-b, pages 106-113)*

The children were able to read WM, mostly locally. They did not often provide responses about the rules' conditions and sometimes they treated the two parts of the picture of a rule as not referring to the same pair of cells or they explained the appearance of new objects in the 'after' picture of a rule by invoking the action of objects that were not included in the 'before' picture. Most often the children read a pair of rules as having no relationship. When they were thought of as related, they were usually considered as describing successive actions. The children used to look for the 'movement' action, even in cases where there was no movement at all. The children's success in reading different WM rules was related to the nature of the situation the rules described ('realistic' or 'unrealistic') and to the degree the rules were familiar to them. Reality was also an issue when the children were deciding about whether or not to reflect on the conditions of the actions and about the level that actions would be described (local or global). Furthermore, the 'abstract' nature of some rules was not much related to the way the children read them. The children always attributed an identity to the objects included in the 'abstract' rules presented to them. Their stories were meaningful and were mostly about successive and specific actions.

- *Can children see the relation between global behaviours and WM local rules? (FMS-RQ-c, pages 120-123)*

The children were able to predict global effects of local rules in certain cases. The main problems they had were that they tended not to consider the interaction of rules and tended to avoid using rules describing unexpected actions such as that if there is a rabbit next to a farmer then it will change to a farmer.

- *Can children replace objects in a WM rule? (FMS-RQ-d, pages 101-103)*

After playing the 'Gardeners' board game, the children were asked to replace one or more objects in three WM rules ('Jump', 'Make new' and 'Changes other object'). Generally speaking, they seemed to be able to explore a rule to a certain extent. The number of the objects to be replaced and the relation between the kinds of action pictured in the rules and the objects suggested as substitutes appeared to be associated with the children's success. An important outcome is that the children were always able to keep the basic structure of a rule intact, correctly representing the appearance or vanishing of an object.

- *Can children draw WM rules for a stated situation? (FMS-RQ-e, pages 113-116)*

The children were able to draw a rule describing a single action such as 'movement' or 'making a new object'. They were more likely to be able to draw a rule if this rule included only one action, had a simple structure and did not involve a change in the properties of the participants. Compared to AgentSheets, when primary school children (aged 8-11) used it, only about half of them were able to use the AgentSheets syntax to express themselves in a science lesson (Rader *et al.*, 1998).

- *Can children create new WM rules? (FMS-RQ-f, pages 103-105 and 116)*

This question was explored in two different tasks. Firstly during the children's introduction to WM by playing the 'Gardeners' board game and afterwards when they were dealing with the 'Gardeners' computer task. Very few children responded to the relevant question of the second task, thus the data available for this research question were collected when first meeting WM-type rules. Even in this case, the children defined a variety of rules that fitted the WM format and most of the actions represented were reasonable. When primary school children (aged 8-14) in the UK tried KidSim (a prototype version of Stagecast Creator) it was found that they were also able to create such type of 'before' and 'after' rules (Cypher and Smith, 1995). One difficulty the children had when defining WM rules concerns a basic WM convention that the 'before' and 'after' pictures of a rule correspond to the same cells. Furthermore, nearly all the actions defined by the children were about 'change of nature' with the 'Jump' rule being defined very rarely. On the contrary, when children from 2nd up to 5th grade used KidSim for creating a model, one of the most favourable rules was found to be about the 'movement' action (Rader, Brand and Lewis, 1997). This discrepancy might be attributed to the fact that the (WM) children had followed a different series of tasks from the US ones. Besides the (WM) children had not seen WM 'in action' when asked to make their own rules, as was the case with the KidSim children.

- *What do children decide in terms of 'possible'/'impossible' WM rules? (FMS-RQ-g, pages 116-120)*

When the children decided about the 'possibility' or 'impossibility' of a rule to be included in a WM model they used two different criteria; one was about the tool used (WM or the computer in general) and the other about the action itself (whether it is/is not 'realistic'). A response that a rule is 'possible' was more likely for an action that had a real world interpretation. In the case of an 'unrealistic' action, if they thought the rule should be included, the children most often focused on some other analogous rules that they had previously seen. This result in conjunction with their ability to keep track of the structure of a WM rule when asked to replace objects in it, was the first encouraging indication of the children's understanding of structures, an issue that was explored mainly in the second main study. Furthermore, the detected tendency that for most children an 'impossible' rule is one that stands for an 'unrealistic' action verifies the results of the preliminary study about children's 'attachment' to reality even when dealing with computer models. In addition, in this study it was found that the children had difficulties in reading a rule about an 'unrealistic' action and in predicting the global effects of such rules. It was a surprise that when reflecting on the possibility of a rule in terms of reality, the children considered as 'realistic' an action that they could imagine. Thus, it is not very easy to sketch what counts as reality for children; is it the children's 'reality' or a reality apart from the person who experience it? Certainly, it is the nature of modelling that allows a modeller to be able to depart from reality. One way to do it is by making simplifications. Actions such as a male is meeting a female, they are having an affair, the female gets pregnant and after a certain amount of time they have a baby, are simply represented by a female meeting a male and having a baby. In a different case, someone departs from reality by refuting it. Although a modeller will never be able to see a zebra eating a lion – regardless of their size – he/she can model it. Enriching reality is another approach. The fictitious reality of video games and movies can be included the same as the non-materialistic world of entities having no natural existence such as news.

9.3.3 Second main study

In this study more regard was paid to a rather broad view of the concept of a WM rule, that is, whether children are able to think of situations in terms of structures. It focused on three of the essential elements involved in the modelling process, namely the situation to be modelled, the computer model and the real world. The children were introduced to the terms *story* and *computer world* (or *'world'*) to suggest the essential features of a situation to be modelled and of a computer model, respectively (see Chapter 7).

The following questions and answers provide a broad picture of my research findings (see Chapter 8) as far as the specific research questions for the second main study are concerned:

- *How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions? (SMS-RQ-a, pages 159-163, 171-172 and 181-185)*

In addition to identifying actions they were asked about (the 'spreading' action where an object A changes to an object B when they meet), the children often correctly described actions they were not asked about (object B changes to an object C by itself). There was a strong focus on actions and conditions of actions, with actions being stronger than conditions. On the contrary, in the first main study it was found that younger children (aged 10-11 as opposed to aged 12-14 before) did not often think of the conditions when accomplishing a different task, the reading of a rule. Furthermore, when even younger children (aged 7-8) used ToonTalk they had difficulties (one of which was to omit conditions) when they were also describing a programmed behaviour even if they had programmed the corresponding rule (Hoyles *et al.*, 2001). In this case, probably condition is an issue if one takes into account the children's age and the kind of task.

- *How do children compare situations? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-b, pages 159-166, 173-174 and 181-185)*

When the children compared situations, their responses did not always fit the WM format with a focus on the actions performed by the participants in specific conditions. The nature of the comparison varied according to whether the children were asked for a similarity or for a difference. They tended to provide 'action' and 'condition' responses when they were looking for similarities between situations that shared the same set of rules. On the contrary, when the same situations were considered in terms of their differences, the children more often looked at the model outcome and the kind of participants.

- *How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-c, pages 159-166, 174-176 and 181-185)*

The children carried out the comparison of a situation to a computer model most often in terms of actions, conditions of actions and the outcome of the model as well. However, these were complementary choices: the comparison tended to be either in terms of actions (with or without conditions), or of outcome, not both. Contrary to the findings of the previous research question (SMS-RQ-b), there was no obvious pattern of response in relation to the question to which the children responded (asking for similarities or differences). In this case, the context of the question seemed to be more related to the type of response.

- *How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-d, pages 159-166, 176-178 and 181-185)*

In comparing situations or computer models with the real world, there was a considerable focus on actions, but not as frequently as in response to the other tasks. And when an action was considered, the children experienced difficulties in defining correctly the relation between the situation or the computer model, and the real world. The amount of attention they gave to different features seemed to be context dependent, suggesting that they judged the realism of a situation or a computer model by a variety of criteria such as actions, conditions, general structure, kind of participants and model outcome, selecting different ones as salient in different cases.

- *How do children compare participants? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-e, pages 159-166, 178-179 and 181-185)*

The easiest way to compare participants, but one that would not be good from the WM point of view, would be to compare them in terms of their kind. However, happily, it was found that less than one fifth of the children did so. Most of them reflected on the changes the participants were involved in, in terms of actions, conditions and general structure and they did it successfully.

- *How do children compare rules? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-f, pages 159-166, 179-180 and 181-185)*

In comparing rules the children although they were provided with the pictures of the 'Changes other object' and the 'Change' rules, they had the weakest tendency to provide 'action' responses. They focused on different aspects of a computer model – actions, conditions, general structure, model outcome and kind of participants. Their choices varied between questions, particularly between questions asking about similarities and ones asking about differences. As in the case of comparing a situation to a computer model, when the children were asked for differences and the compared rules had the same structure, they considered the kind of participants and the outcome of the model more often than the actions in the rules. Although the pictures of rules were provided, the children did not compare the rules in terms of the correspondence between the participants. The same tendency was also detected when the children compared participants.

- *Given a set of purely 'abstract' rules, how do children predict whether outcomes are possible or not? (SMS-RQ-g, pages 159-166, 180-181 and 181-185)*

The predictions the children made about possible/impossible outcomes were based on the actions and the conditions of actions pictured in the 'abstract' rules. Particularly in the case of conditions, the children focused on conditions when they needed to. This is a result that might be expected as any valid prediction had to be based on the actions and the conditions pictured in the rules. At the same time, dealing with the 'abstract' rules, the children had the weakest tendency to reflect on the correct actions, but on the whole, it is perhaps striking that they dealt well with these questions.

- *Is children's tendency to look for actions and conditions of actions related to the nature of the situation considered? (SMS-RQ-h, pages 171-181)*

The level of context dependence was very low when the children were deciding on which modelling feature of the situations presented to them they would focus on – actions, conditions, general structure, correspondence between participants, model outcome or participants (kind and number). But, the children had difficulties (again and again) in correctly identifying the above features when comparing an 'unrealistic' situation and the corresponding computer model with the real world and with each other. On the contrary, in the case of reflecting on a situation where the participants were 'abstract' objects, the level of success was higher.

- *Is children's tendency to look for actions and conditions of actions related to the kind of question to which they respond? (SMS-RQ-i, pages 171-181 and 181-185)*

The children's tendency to look for structures was very strong when they were clearly asked to focus on specific actions. In the case that broader issues were under their consideration, such as the relation between situations, or situations and the real world, the children found 'attractive' other features as well, such as the participants' kind or the model outcome. Furthermore, across questions of the same group, the children did not always have a similar tendency to focus on actions and conditions of actions. In the case that pairs of questions – one question asking for similarities and the other for differences – were included in a group of questions, then the children provided different patterns of responses.

- *Can children draw WM rules for a stated situation? (SMS-RQ-j, pages 188-189)*

Most of the children were able to draw the rules describing two different situations (one 'realistic' and one 'unrealistic') which, although they had different contexts, shared the same kind of rules. Actions and conditions were very often drawn correctly to represent a change in the nature of the participants as well as a change in one of their properties. From the modelling perspective, the fact that the children most often could draw the actions involved in the 'unrealistic' situation correctly, although they had problems in successfully identifying them in previous tasks, was a 'welcome' surprise.

- *Can children understand and use rules in abstract form? (SMS-RQ-k, pages 157-159, 159-163, 163-166, 180-181 and 181-185)*

The children were successful in dealing with 'abstract' rules. On the whole, they were able to identify correctly the actions and conditions pictured in the rules, especially in the case that the 'Changes other object' rule was under consideration. The way that children's understanding of 'abstract' rules was approached – by asking them to predict the outcome of 'abstract' rules – should be an issue when reflecting on children's ability to understand and use rule in abstract form.

- *What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them? (SMS-RQ-l, pages 157-159, 163-166, 176-178 and 189-192)*

When the children were deciding if a situation or a computer model was meaningful to them, they most often considered its relation to the real world. They often expressed this relation in general terms without making reference to specific characteristics of the situation or the computer model. But when asked to write their own situation that 'makes sense', the children were less 'conservative' and produced both 'real world' and 'fantasy' situations. Thus, 'making sense' was not so strongly tied to 'making real world sense'. The rules and actions chosen varied between 'real world' and 'fantasy' situations. When the situations had a real world interpretation, the 'changing by itself' action was more often used. In the case of their 'fantasy' situations, the children used the same set of rules ('Changes other object' and 'Change') as in the 'fantasy' situation previously presented to them.

- *What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful? (SMS-RQ-m, pages 193-203)*

When the children were asked to think about reasons why a computer model might work or not, they were willing to identify the rules – their presence or their appropriateness – as the main factor determining the effectiveness of the computer model. In the case of an unsuccessful computer representation of a real world situation, the children were able to identify not only possible causes of failure but also actions – to add or to change a rule – that dealt with the causes. If an 'unrealistic' situation was under consideration, then the lack of success of the computer model was attributed either to the way the rules were defined ('formal' reasoning) or to supposing that only rules about 'realistic' events can work ('semantic' reasoning). The tendency for the second type of reasoning was slightly stronger than the first, but both were present. On the whole, the children were more likely to agree with several reasons why a computer model can fail, rather than to pick just one. In addition they generally supported the notion that in order to improve a computer model one should think about things before choosing what to do.

- *Can children create a WM model using WM objects and rules? (SMS-RQ-n, pages 203-207)*

The last research task required the children to create a WM model for a forest fire by choosing the appropriate objects and by defining the necessary rules. Although one might have assumed that the children would be able to create their own computer models after considering their performance in the previous research tasks and the modelling experience they had already gained, it ended up being the hardest task of all. The children were able to give reasonable accounts of what might happen during a forest fire but they had difficulties regarding the appropriateness of the objects they used in their own WM models and the actions they defined. Quite often, in a single rule there were objects representing global effects (e.g. 'whole forest' or 'burnt forest') and objects appropriate for local actions that would lead to such global effects (e.g. 'a tree on fire'). In this case, the children had difficulties in identifying the specific interacting objects that produced the specific global behaviour. Wilensky and Resnick (1999) talked about the confusion of levels and cited it as the source of people's misunderstandings about patterns and phenomena in the real world. Similarly, when 2nd up to 5th grade children used KidSim to create science models they had difficulties in decomposing a situation into participants with actions (Rader, Brand and Lewis, 1997). When drawing the 'Fire spreading' rule, the children used the object 'fire spreading' to declare the spreading of a fire. Then, they seemed to abandon the very basic WM principle that the only way to show such an action is to use different objects in the 'before' and 'after' pictures of a WM rule. Furthermore, problems that were acknowledged before regarding the definition process of a WM rule were also identified here, such as the children's misunderstandings that the cells included in the 'before' and 'after' parts of a WM rule are different or that the appearance of new objects in the 'after' picture of a rule is not always the outcome of the interaction between the objects in the 'before' picture. These difficulties might be attributed to the wording of the task (global picture of a forest fire) or to the children's insufficient modelling experience during the research.

9.4 Answering the general research questions

The data collected in the different stages of my research (preliminary, first and second main study) may come together to answer the general research questions.

- *Can children understand, use and think about models in a WM form? (GRQ-a)*

There are two main issues related to children's understanding, use and thinking of models in the WM form: (a) their ability to see the world around them in terms of changes and (b) to represent these changes in terms of WM rules using the WM syntax.

These issues were explored by the following specific research questions:

a. Can children read WM rules? (FMS-RQ-b)
b. Can children see the relation between global behaviours and WM local rules? (FMS-RQ-c)

c. Can children replace objects in a WM rule? (FMS-RQ-d)

d. Can children understand and use rules in abstract form? (SMS-RQ-k)

The children were found to be able to pick up easily the basic idea that models in WM concern processes of action and change (as opposed, for example, to just picturing a situation). Thus, they looked at the rules as describing actions or interactions merely locally. Being provided with the pictures of rules, the children seemed to accept them as broken-down actions and thought of them appropriately, regardless of the nature of the participants (specific or abstract). Similarly, when KidSim was introduced to 2nd/3rd and 4th/5th grade students, it was found that the majority of the oldest and less than half of the youngest understood that rules control behaviour and the meaning of simple rules (Rader, Brand and Lewis, 1997). In the case of WM, the children were able to give an account of the action pictured by a rule, even in the case of exploring it by replacing the participants. However, they did not find it easy to accept the deterministic nature of rules according to which the appearance or disappearance of an object from the grid is possible only if it is the outcome of the action/interaction of the objects initially appearing on the grid and only specific kinds of actions are allowed. The children's attention was drawn to what changes and not to what stays the same. Thus they focused more often on the 'acted on' objects (those being changed by other objects) defining a rule in terms of the actions included, rather than on the 'acting' objects (the ones that change other objects) defining the conditions of the actions. Furthermore, the children had difficulties in thinking about the consequences of more than one action. They were also rather 'selective', keeping aside and not considering those rules that were about 'unrealistic' actions. There was also one more aspect of the WM syntax that was hard for the children to anticipate, the fact that the cells pictured in the 'before' and 'after' pictures of a rule are the same.

- *Can children think about situations in the 'modelling' way required by WM, that is, in terms of objects and rules? (GRQ-b)*

This question mainly concerns children's ability to see the world around them in terms of structures, which can be represented by WM-type objects and rules. Three different types of research question explored this issue. The first type includes the following two questions:

a. Can children draw WM rules for a stated situation? (FMS-RQ-e and SMS-RQ-j)

b. Can children create new WM rules? (FMS-RQ-f)

How successful the children were in the drawing tasks seemed to be related to the kind and number of the actions included in the situations. The fact that a situation was about a change in the nature of the participants or in their properties was difficult for the youngest children with limited 'modelling' training. In addition, the children were found to be able to create new WM rules, mostly about 'change of nature'.

A second group of research questions was looking for children's ability to think of a situation in terms of actions and conditions of actions. These questions are:

a. How do children describe the way a computer model or a situation works? Do they describe them in terms of actions and conditions of actions? (SMS-RQ-a)

b. How do children compare situations? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-b)

c. How do children compare a situation to a computer model? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-c)

d. How do children think about the relation between a situation or a computer model, and the real world? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-d)

e. How do children compare participants? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-e)

f. How do children compare rules? Do they compare them in terms of actions and conditions of actions? (SMS-RQ-f)

g. Given a set of purely 'abstract' rules, how do children predict whether outcomes are possible or not? (SMS-RQ-g)

h. Is children's tendency to look for actions and conditions of actions related to the nature of the situation considered? (SMS-RQ-h)

i. Is children's tendency to look for actions and conditions of actions related to the kind of question to which they respond? (SMS-RQ-i)

The above questions formed the basic research corpus of the second main study. A network (see Figure 8.1) was devised and used as a tool for distinguishing different types of response to the tasks designed to answer these questions. However, the network is in a sense also itself a result of the research, in that it describes the kinds of difference in the responses that the children gave. Amongst these are differences in levels of response, indicating different levels of understanding of the process of modelling. Specific elaborated features identified in the children's responses (see subsection 8.2.3.1) correspond to each level. These levels might be categorised as follows:

Modelling level	**Elaborated feature**
Basic	Model outcome
Intermediate	General structure Correspondence between participants
Advanced	Action Condition of action

Table 9.1 – Levels of understanding in the children's conceptualisation of models

According to Table 9.1 above, when the children focused on the outcome of a model, they exhibited a basic level of understanding of models since a 'model outcome' response expresses at least an appreciation of the fact that WM models concern changes. From there, probably the children would be able to move towards the most advanced modelling level by explaining the mechanism under which the specific outcome occurred – to talk about why something happens in an 'action' and/or 'condition' response rather than about what happens in a 'model outcome' response. When the children provided a very global and general description of an action and/or when they reflected on the placement of the participants in the picture of a WM rule, although they looked at actions, they did not specify them. Even though this level of description reveals an understanding of the structure of a model, it is not sufficient for making a WM model. Such kind of response indicates an intermediate level of modelling understanding.

It was found that in most of the tasks of the second main study the children had an advanced level of understanding of the modelling process when they reflected on actions (conditional or unconditional) and conditions of actions more often than on other features. This tendency did not seem to be context dependent – the situation modelled might be 'realistic' or 'un-realistic', specific or 'abstract' participants might be involved – but it was more related to the kind of question the children responded. Besides, the pictures of rules did not encourage the children to focus on actions and conditions of actions. Often the children's responses were not 'correct' – in this case the context was an issue – but they were looking in the right direction. The fact that the children were willing and very often able to look for the underlying structure of a situation ('realistic' or 'unrealistic') or a computer model is an important finding and very encouraging for teaching modelling to children of this age range. Especially in the case where the children were comparing situations which were different in everyday life, so that the children could not use the similarity of the context as a hint of the similar structure. But according to Millar and Driver (1987, p. 48),

> "*It might appear that what is required for this to happen is for a learner to be presented with a number of examples of a particular phenomenon or event in order to note a general pattern in the observations. (For example, noting the effect on the size of the image in a pinhole camera is brought closer to the object.) Simply noting a relationship of this kind, however, does not mean that learners have constructed a model to interpret the problem.*"

This comment could probably put a limitation to my research findings. Although in this research, the children were asked to identify general patterns considering different situations and making comparisons at different levels, the critical activity of asking children to build a computer model to describe the different situations was not carried out due to the limited time available for the children to become familiar with WM. If otherwise, more evidence would be available for the children's ability to use a WM rule as a structure to identify and present regularities across different situations.

The final research question looking for children's ability to think in the WM 'modelling' way is the one that follows:

- Can children create a WM model using WM objects and rules? (SMS-RQ-n)

For this question, the children had to design the WM model of the spreading of a forest fire. The identification of the elements of the model was the first step they had to take and according to Millwood and Stevens (1990) it is one of the hardest things to do, particularly for beginning modellers. Even so, the children had some success in choosing the right kind of objects that could represent local actions to create a WM model.

- *How do children see the relation between models and the real world? (GRQ-c)*

The children, who participated in this research, cannot be seen as 'ideal' modellers who are willing to model any situation regardless of its nature ('realistic' or 'unrealistic'). There is a borderline between reality and fantasy that the children were not willing to cross even in the case of playing around with a machine. Rader, Brand and Lewis (1997) call this reasoning *experience-based reasoning* according to which objects should behave as they do in the real world, and they identified it when young children worked with KidSim. Although one might expect they would enjoy changing the existing order of things – wouldn't it be fascinating to see fishes eating sharks? – the children were 'conservative'. There are frames of everyday knowledge they did not want to abandon or to question, even in the context of a computer model, even though they knew they were the ones creating it. At the same time, what children can imagine plays a significant role in defining a situation as 'realistic' or 'unrealistic'.

There were a number of research questions addressing the issue of how children see the relation between models and reality:

a. What do children decide in terms of 'possible'/'impossible' WM rules? (FMS-RQ-g)
b. What, for children, counts as a situation or computer model 'making sense'? Do they consider the real world when they create their own situation that 'makes sense' to them? (SMS-RQ-l)
c. What do children think about the reasons why a computer model works or not, and what do they think should be done about models that are not completely successful? (SMS-RQ-m)

In the corresponding tasks, the children had to consider rules ('People flying'), situations ("Does this story makes sense?") or computer models ("Does this 'world' make sense?"). In each of these cases, a sizeable proportion (50%) of the children saw models and reality as closely related. Thus those children were more likely to say that you cannot define a WM rule showing people flying because "… people don't fly. Only angels". Similarly, a situation that 'makes sense' is about "The baby caterpillar could change to a normal size caterpillar, then it can change to a butterfly". Finally, reflecting on a computer model about rabbits, they would agree with the statements "*Your 'world' is no good. It has a rule where rabbits eat foxes, and that doesn't make sense. It could not happen*" and "*It is more important to get rules which make sense than to get the 'world' to do what you want*". It is worth noticing that these questions were given to the children when they had modelling experience with WM. This finding supports the findings of others (Grosslight *et al.*, 1991; Bliss, 1994c; Raghavan and Glaser, 1995; France, 2000) investigating children's understanding of models. They also found that children are not easily able to draw a line between a model and the reality it models.

The other 50% of the children, under the same circumstances, decided that it is possible to see fishes eating sharks "because yesterday you could see farmers catching rabbits", to write a situation that 'makes sense' about creatures "that change into whatever touches them", to decide that a situation about cats that change to dogs when they meet each other 'makes sense' because "with the computer you can make it do anything you want. To the computer it makes sense, to me it doesn't", and when reflecting on an unsuccessful 'crazy' computer model about boats and sharks to agree with those claiming that "*My 'world' doesn't work because I've got the rule wrong*" and "*If you want to get the 'world' to do what you want, you should get the rules right, regardless if they make sense or not*".

More specifically, in the case of the modelling questionnaire, it became obvious that the children were likely to agree with several options exploring the relations between situations, computer models and reality, rather than to pick just one. In the case where they did, then they were consistent. Most of the children were also mature enough to realise that in modelling one should think about things before choosing what to do. A good majority also rejected extreme arguments, such as the hypothesis that in the case of an unsuccessful computer model, all the rules must be wrong.

9.5 Carrying out modelling activities with WorldMaker

Although the term *model* refers directly to the 'creation of a model' process, in an educational setting there are other activities (i.e. description and explanation of a model's formal behaviour, interpretation of the meaning of a model and exploration of a model), in which a model might be involved. In this research, WM was the modelling tool used. To decide about how 'successful' it was, I shall consider the children's performance when dealing with different modelling activities.

Most of my research questions investigated the way children describe and explain a model as far as its rules are concerned. Three different aspects of the concept of a WM rule were explored. The first is related to probably one of the most essential features of a WM rule; the fact that it describes a situation in terms of actions performed by specific objects. An action corresponds to a change in the position or direction of the objects, or in their nature. The other is about one more attribute that rules have, that is to describe an action by providing a picture of it in terms of 'before' and 'after' states. The last one has to do with a facility offered by WM, the fact that although the rules describe local actions, they can usually produce rather predictable global effects.

In the research it was found that when considering a situation or a computer model, mainly for carrying out comparative tasks, there was a considerable percentage of young children that ignored surface features such as the context from which the situation was drawn or the kind of the participants, and looked for structural relations. These structural relations were expressed mainly in terms of the actions performed by the participants in the situation, less often in terms of the necessary conditions, and they were such that they could fit in the structure of a WM rule. In addition, the picture of a WM rule ended up being a successful representation of an action. Basically, the children were able to extract the right kind of information from the picture of a rule. Nonetheless, according to the children rules and structures were not closely related. Therefore, when designing modelling activities for children one should give more thought to which stage to introduce them to the picture of a WM rule.

The children had difficulties in making predictions regarding the global effects of local rules when considering rules drawn form an 'unrealistic' situation. However, their performance was much better when 'abstract' rules were considered. In this case, no more than two rules had to be considered and the outcome of a computer model had to be defined in terms of the kind of the participants and not of how many there were. This discrepancy could be attributed to children's difficulty to consider more than two rules at the time, to the level of the global description (kind or number of participants) and to the nature of the situation considered. In any case, probably the abstract nature of the objects helped the children to focus on the rules for making their predictions or simply reading them, as they did not have any expectations for what actions the objects might perform.

A second group of questions was about the creation of a model using WM rules. The children were either given the situation to be modelled and they had to draw the rules, or they decided on their own which situation it was going to be. Although the questions investigating this issue were given to children who had different degrees of familiarity with the process of defining WM rules, some general trends can be identified.

The creation of a model is regarded as probably the most demanding modelling activity. This research reveals some of the possibilities and difficulties young modellers might encounter. It is encouraging that young children found the task of making the model of a situation meaningful, and regardless of how successful their models were, those models could stand as representatives of the situation. This is not a surprise as modelling activities are part of children's everyday reasoning as soon as their 'encounter' with the world around them begins. But this research shows that children as young as primary school age are able to exercise this way of thinking in a more formal setting. This is an issue that has also been raised for the modelling tools most 'kindred' to WM, such as AgentSheets and Stagecast Creator (see subsection 2.3.3.1). Besides, every tool imposes a specific way of 'looking' at things. Unsurprisingly, it was found that the way of thinking in terms of objects and events could be applied by such young children. Moreover, the design of the computer-based modelling tools meant for young children, from the 'mama' Logo to its children StarLogo and Squeak, as well as to its cousins such as ToonTalk, AgentSheets and Stagecast Creator (see subsection 2.3.3), was based on young children's 'materialistic' thinking. Furthermore, verifying the results of other studies involving AgentSheets and Stagecast Creator (see page 214), the definition of events in terms of 'before'/'after' rules is a manageable task for young children, who are able to see an event as an action on an initial state to produce a new one. Then, probably children possess the corresponding Piagetian schemes or mental models (see section 2.4), which permit them to see this transformation of the objects' state.

The present research was more innovative when suggesting that young children aged 12-14 were able to use the structure of a WM rule to describe situations, which although they looked different, were defined by the same set of WM rules. The fact that a good proportion of the children were able to apply this way of thinking makes clear that children are able to take a further step in modelling, to identify the 'general' when looking at the 'particular'. Then, the creation of a model could be a twofold process; it could be about how to represent a particular situation and afterwards about how to represent this representation in an abstract form.

The difficulties children experience when creating models arise from the fact that the way children think and the way any modelling tool asks them to think is very hard, if not impossible, to coincide, even in the case of taking for granted that children of the same age range reason similarly. There are difficulties occurring whenever children are asked to work with any computer-based modelling tool. Then, they have to be very precise, stable and mature enough to accept all the conventions imposed by the tool – "*you can do this but you cannot do that, this is the way you should do it*". If this is a hard thing to do for an adult, imagine what it is like for a young child who has very limited experience on controlling devices. Furthermore, Piaget's remarks about the way children of this age range handle the concept of a rule (see section 2.4) – although referring to a social context – were verified in this research. In agreement with his findings, it was noticed that according to children aged 10-14 the WM rules, which they can define and change, control the actions on the grid. What was also found was that for quite a few children the actions on the grid should have a real meaning. Taking into consideration the terminology used by Hoyles *et al.* (2001) – see subsection 2.3.3.3 –, in this case the children invented a *player* rule (you can only define a 'realistic' situation) and used it as a condition for the implementation of a *system* rule (such as the 'Changes other object' rule). Working with children aged 7-8 Hoyles *et al.* (2001) came to the realisation that children might not predict the consequences of formal rules unless the narrative makes sense. Although older children participated in this research, it was found that the nature of the situation at hand was an issue.

Besides, some further difficulties are related to the process of identifying the participants and the actions they perform. The children were able to understand an action that takes place on the grid and to follow the changes as they occur – a grid is divided into cells and the change of the state of the cells indicates the actions that take place. Actions in WM are local and even though a group of objects might perform the same action, this action has to be defined for one object representing the group. The children had no problem in representing rabbits jumping around by one rabbit jumping from one cell to the other. However, making a model of a situation such as "*healthy persons meet ill persons and change to ill*", was much easier for the children than a situation such as "*a disease is spreading*". The children ended up having great difficulties in explaining such a global behaviour in terms of a single local action.

Regarding the drawing of rules, the children found it hard to use the WM convention that a rule depicts the same two cells before and after the action takes place. Furthermore, although it is in the nature of WM that it is necessary to specify the conditions for the actions to take place and that these conditions are only related to the 'proximity' of the objects, the children often avoided thinking about conditions.

The interpretation of the meaning of a model was also explored in this research. There were questions asking children to confront reality with 'artificial' reality. But the children were young and about half of them did not yet know where the boundaries were. Without having yet anticipated what is reality and what counts as real, they had difficulties in accepting the fact that there is an 'artificial' world that we, the humans, create and control. Therefore, when children are introduced to modelling, it might be better to avoid asking them for the 'meaning' and the 'making sense' of the models. It might be the case that after having enough experience in creating 'artificial' realities they will have a better chance to handle these issues.

The exploration aspect of the modelling process was not broadly investigated in this research. There was only one question asking children to replace objects in a WM rule. It was found that in the context of a board game, the children were willing and able to create rules in which the participants were not behaving in a meaningful way, unless these rules are seen as describing a variation of the board game presented to them before. Then, probably such an explorative activity followed by the implementation of all the rules the children suggested would be a helpful way to introduce them to the interpretative aspect of the modelling process.

On the whole, it was found that the children were able to use WM to carry out a number of modelling activities. The amount of time spent to become knowledgeable about the tool was vital. Although they were able to familiarise themselves with it in a short and reasonable amount of time, some of the difficulties they met when creating a model could be attributed to insufficient training. It would be an exaggeration to conclude that the creation of a model is an impossible task for young children. Instead, in order to help children to overcome some of the obstacles they have, more time with the modelling tool is necessary together with a more thoughtful design of the modelling activities that takes into consideration the way children think and learn when interacting with a computer-based modelling tool. Furthermore, this research demonstrates that although the modelling process is very much attached to the modelling tool used, there are aspects that are 'universal' and should be considered before children are invited to take part in any type of modelling activity.

9.6 The relevance of modelling with WorldMaker

Let us consider a young child and a scientist who think about an aspect of the real world. In the best case, the first will be able to understand what the science says about the specific phenomenon whilst the second may be able to make his own contribution to scientific knowledge about the phenomenon. If that is the case, do these two endeavours have anything in common? Both involve the real world and the respective scientific knowledge. But a child is expected to be 'conservative' as opposed to a 'reformer' scientist. If taking into consideration the fact that a piece of scientific knowledge might be the outcome of a process that has four components – (1) an aspect of the real world, (2) a model, (3) some predictions deriving from the model and (4) some data coming from the real world (Giere, Bickle and Maudlin, 2006) –, then the scientist is a 'reformer' when he makes and evaluates a theoretical model – sometimes by reconstructing the existed one. The child can not be anything other than 'conservative' because it is not able to contribute in any way to the production of new pieces of scientific knowledge. Then someone might say that it is useless for a school child to try to accomplish the above process. But, wouldn't the young child be a 'reformer' of its own scientific knowledge, if it was given the opportunity to make, express and then reconstruct if necessary its own and sometimes unique model about specific aspects of the real world? Furthermore, are the scientists by their nature able to cope with models? Is it a special gift that they have from birth? According to Duschl *et al.* (2007) many aspects of the making models process do not emerge without explicit instruction and opportunities for practice. Then, the need for a learning situation, where modelling is an issue, comes forward.

Under this perspective WM is a modelling tool that might be of some use. An outcome of the research is that WM satisfies two preconditions as stated by Bliss (1994a). One is that it allows the expression of children's thoughts in the form of a WM rule, and the other is about children's ability to use the form of a rule to identify similarities and differences between a situation, a computer model and the real world or in other words to define the analogies between the above in terms of structural rather than surface relations. Then, in the case of science, WM can be used to teach children science; about science and how to do science (see subsection 2.2.1). A WM scientific model might be built and children could be asked to draw the analogies between reality and the model. This could help children to appreciate that a model may stand for the real world but it is not the real world. According to Gilbert and Boulter (1998) this will help children to develop a better understanding of the scientific knowledge. Or, in a learning situation as defined by Millar and Driver (1987), children might build a WM model to express the representations they have prior to teaching, something that will facilitate the learning process. From Gilbert's and Osborne's (1980) perspective, WM can be used to familiarise children with the making models process, in order to get them accustomed to the scientific way of reasoning. Finally, Gilbert (1991), and Justi and Gilbert (2002) suggest the use of models to teach children about the nature of scientific models. WM can also play this role.

But WM is not the only tool available for use by young children (see subsection 2.3.3). In that case a need emerges in research to compare different modelling tools to identify which modelling aspects they support well or less well.

9.7 Outline advice for a teacher wanting to use WorldMaker

In view of the fact that WM was used by a considerable number of primary and beginning secondary school children in different learning contexts and using different research tasks, issues concerning the problems and the opportunities children have when using it arise from the analysis of the children's responses. As a result, some recommendations might be made about children's introduction to the tool and the tool's integration into the curriculum.

Obstacles in learning how to use WM

When children are using WM for the first time, the first step is to get accustomed to its interface. They have to familiarize themselves with commands such as opening, running, stopping and saving a model, plotting and removing a filler and so on. The children did not have any great problem in acquiring these skills. Attention needs to be paid to practising these commands, which have to do with the process of modelling a situation on the computer and which have no correspondence with children's involvement when the same situation takes place in real life. For instance, actions such as plotting on the grid a block of fillers and clearing the grid with just one mouse click look like magic tricks in real life. Another example is the necessity when working on the computer to stop the model before making a change such as to plot a filler, which again in reality is impossible – life goes on; reality cannot be stopped. Learning how all the different commands are displayed on the computer screen is the next step regarding the interface. Wherever the symbolic representation of tools is arbitrary (for example, why does ■ represent the 'block' tool?) time has to be allowed for children to become familiar with them.

Later, when dealing with the concept of a WM rule, other issues are raised. An outcome of this research was that according to the children the two cells pictured in the 'before' and the 'after' parts of a rule are not the same. A teacher might help children to overcome this difficulty if, before presenting the picture of a WM rule – horizontal arrangement of the cells –, the rule is presented with the cells arranged vertically. Then children might be able to more easily make the correspondence between the cells in the 'before' and the 'after' pictures in order to make the comparison of the state of the cells before and after the action. Another issue emerging from this research is that the children avoided thinking of conditions. They tended to think of actions and conditions of actions when the elements to be compared differed in terms of conditions. Thus, a teacher might help children to focus on conditions of actions if, as a practical exercise, they have to compare situations (by pointing out the differences), computer models, rules or participants where the same action is related to different conditions. In Stagecast Creator, children's (aged 10-12) understanding about conditions was clarified when not only conditions in the rules were explained to them but also when the rules governing the relationship between the user and the game were explained (Martin, 1999). Probably, such a teaching approach might help children to anticipate the 'necessity' to define the condition of a WM rule. Furthermore, helping children to grasp that 'proximity' is the only available condition for WM is not an easy task unless it is presented as a restriction.

How to introduce WM to children?

In the research WM was introduced in two different ways. In one case (i.e. preliminary and second main studies) the children became familiar with the tool through carrying out specific tasks on the computer. The WM interface and the essential elements for making a model (i.e. fillers and rules) were presented simultaneously. In the first main study, where the emphasis was on children's understanding of rules, there was an introductory session in which the children dealt with a board game. A game board was used divided into squares – in the same way as the grid is divided into cells – and the children moved the chips according to a WM set of rules. They practised replacing the objects in the rules and defining their own rules. Then they moved on to the computer and the remaining (paper and computer) tasks. Although the research was not designed to identify the most effective way to introduce WM, it was expected that the board game would help children to become familiar with the concept of a rule. It was found that the children were able to pick up the idea of an action, that their actions were reasonable, that they used the idea of 'proximity', but that only some made the 'before' and 'after' pictures of a rule to refer to the same pair of cells. Thus this approach worked quite well in some aspects and not quite so well in others. Yet it does show that the use of simple and familiar means, such as a board game (children being familiar with games such as draughts), as an introductory session to WM computer modelling might help children to overcome some of the problems they have regarding the concept of a WM rule.

Finally, the degree of freedom a teacher should provide to children depends on what he/she is aiming for. The twofold approach, to teach the modelling tool and at the same time to familiarize children with the modelling process, does create problems and misunderstandings for young children. On the one hand, children are being asked to learn, understand and be able to use a computer program which however 'friendly' it is, imposes on them certain restrictions of what to think about and how to think about it. On the other hand, children are being asked to change models or even to create their own. And, as might be expected children have not got the experience and the maturity to adjust what they want to do to what they are allowed to do by the program and to anticipate the very basic fact that in computer modelling no filler has a priori any attribute, no change ever takes place unless the modeller defines it. It seems likely that the teaching of WM and the teaching of modelling should not take place simultaneously so that children of this age range do have the chance to work more systematically on the specific program and on modelling in general. Children's introduction to WM using a board game is a step in this direction; it is a way of introducing children to a basic concept of WM, that of a rule, without asking them to deal with the modelling process at the same time.

What can you do that is new/different?

WM is a modelling tool that might be used from primary to secondary education, teaching children very basic modelling aspects, or more complex ones in the context of a science lesson about the spreading of diseases or about radioactive decay. The introduction of WM in schools can offer children the chance to deal with these phenomena in a simple and manageable way, in terms of objects and actions, an option that up to now has not been offered by many modelling tools. Possibly one of the most important advantages is that WM enables children to see the world in a unified way. Children are encouraged to, and indeed are able and willing to go beyond the appearance and basic nature of particular phenomena, looking for underlying structure and similarities. Children's realisation that a simple WM rule such as 'Changes other object' describes the mechanism of the spreading of diseases during an epidemic, of news when rumours are going around, of a forest fire when a whole forest is burnt down, is probably the first step towards the level of thinking that scientific laws demand. Using WM in the classroom may encourage children to move from concrete thinking to a more abstract level, necessary for some of abstractions they have to make.

Where does WM fit in the curriculum?

WM has been tried in primary and secondary schools to teach mainly concepts related to science. The existing models (see subsection 2.3.2) correspond for the most part to two programmes of study of the current National Curriculum for science (DfEE/QCA, 1999b) where Information and Communication Technology (ICT) involvement is recommended. One is about life processes and living things showing changes of populations, effects of competition and predation, and the other about materials and their properties showing models of the atom and reaction. Although there are limitations on its uses as a teaching tool – in WM only particular actions performed by discrete objects are allowed – probably one of its advantages is derived from this inadequacy. As this research has shown, children of primary education can bring WM into play to model very simple actions and they are keen to do so. Therefore it could be used as a tool to teach modelling. Taking the perspective of the National Curriculum for ICT (DfEE/QCA, 1999a), the tool could be used initially with young children as an explorative tool and then as they progress as an expressive one. This could be beneficial for a science classroom in which explanations related to models are the accepted practice.

9.8 What I found out during the conduct of my research

WM is a computer-based modelling tool and as such it can be used to teach modelling for its own sake or as a vehicle to support teaching and learning via modelling in specific areas of the school curriculum. If emphasis is placed on children becoming acquainted with basic computer science concepts, WM might be used as well as a computer-programming tool. Although these approaches to WM might be seen as being different in terms of the teaching objectives they have, there is a substantial teaching purpose they share; they ask children either to think like a computer or at least to learn how a computer 'thinks'. According to Smith, Cypher and Tesler (2000, pp. 77-78), "*This radical refocusing of the mind's eye is difficult for most people. Even if they learn to do it, they don't like where they end up. They* *don't want to think like a computer; they want to control computers to accomplish tasks they consider meaningful*". Even though WM was designed to be close to the way children think – a situation is described in terms of objects and what they do, actions are defined in terms of qualitative and pictorial rules which are analogical in nature, simple computer manipulation is demanded – there is enough evidence in this research to suggest that what Smith, Cypher and Tesler (2000) say can also be applied in the case of WM.

When dealing with the research tasks, there were a considerable number of children, who insisted on seeing the computer as an 'annex' to reality. They were the ones who rejected the possibility of representing an 'unrealistic' situation in a computer model and who wanted things to work in the computer the same as in real life. And there are some basic features of WM that contradict reality's 'regulations in force'. Even though in reality there are actions that are not initiated by people – the sun rises and sets, people are born, grow old and die – in WM no action ever takes place unless it is defined by the modeller, who has to play the role of God or nature. Despite the fact that in real life there is an unlimited number of actions and conditions of actions to be performed, WM allows only a few actions and conditions – 'adjacent' is the only condition for a WM action while in real life it is not. In WM (as it is currently implemented, but not necessarily) the properties of the participants in an action cannot be represented; a healthy and an ill person have to be represented as two different participants. In the real world regardless of the persons' health condition, they still have the same nature; they are humans. Although in real life it is meaningful and pretty much understandable for a child to think of an action in terms of its final outcome – when asked, a child may describe a school day as waking up, going to the bathroom, having breakfast, going to school, etc. – in WM, actions have to be defined in terms of their 'before' and 'after' states which also specify the necessary conditions for the actions to take place. In spite of the fact that in real life the description of an action may involve objects for which one is a subset of the other, for instance, a pupil and a whole class in a description like "*the diseases was spread to the class by a sick pupil*", WM does not allow such a kind of description to be defined by WM rules. In WM, the above action has to be defined as "*the disease spreads when a healthy pupil meets a sick one*". Some of the above discrepancies between the way situations are modelled in WM and the real world concern any computer-based modelling tool and others are only related to WM and other similar tools like AgentSheets and Stagecast Creator. It is apparent that when WM or any other modelling tool is introduced to children, firstly they have to anticipate that it does not work exactly as nature does and then to come in terms with the way the specific tool works.

Nevertheless, despite the differences between the way children think and the way WM asks them to think, this research showed that a good proportion of the children were able to make this shift. While working in a real life setting – themselves, a teacher and a computer – they were willing and able, up to a certain level, to set their own computer model or to explore one created by others. Two encouraging facts arose from the research. The first is that the children had no great difficulty in using WM syntax to define situations. The other concerns a more fundamental aspect of children's reasoning, which is about their ability to think about situations in terms of actions and less often in terms of conditions of actions. This kind of reasoning could also be useful in representing situations using at least one of WM 'kindred' tools, namely AgentSheets or Stagecast Creator. Furthermore, it was found that the children were able to look for actions when considering situations about different events, having different kinds of participants and different outcomes. Then, they compared situations using decontextualized structures that could stand for abstract forms of WM rules. This kind of thinking and reasoning is very useful for children's later development of the cognitive skills necessary to cope with scientific knowledge expressed as a physics law or a mathematical theorem. It is also a useful tool in helping them to employ models in their own explanations of phenomena. Moreover, the breaking of situations into actions and the presentation of the actions as WM rules ask children to follow an analytic way of thinking. According to Dreyfus and Dreyfus (1989), this way of thinking is only a variation of human thought. They point out that if not seen as such, then there is a case that "... *it would leave the learner a perpetual beginner by encouraging dependence on rules and analysis*" (p. 141).

Of course there are many limitations of my research findings. There are aspects of children's modelling abilities I did not investigate. For instance, issues such as children's ability to test the models they create, to evaluate them as they run and to suggest what changes have to be made on them, might also have been included in my research objectives. Besides, the modelling abilities investigated were explored for specific situations and WM rules, thus there is a concern about the applicability of the research outcomes. As the number and age of the children participating in the three stages of the research were not the same – in the preliminary study a group of three children aged 10-11, in the first main study fifteen groups of two children aged 10-11 and in the second main study 124 children aged 12-14 – and they also had different modelling training, the outcomes emerging from the different stages of the research have a different validity. The validity issue arises within each research stage due to the fact that a different number of questions investigated each issue.

In the end, without any doubt, the identification of the basic primitives of children's thinking has been a long standing process that has attracted the attention of people coming from different disciplines and which has resulted in some very well known cognitive theories about how children think and learn. This research was based on some basic principles regarding the way children think, but at the same time it has shown that when computer use is involved, it cannot be taken for granted that children think as they might be expected to think. Besides, as new tools for teaching and learning are designed, the need to adjust the long-standing cognitive theories to the new ways of thinking demanded by the tools becomes apparent.

It is regrettable that the research, which anticipates much that others have done since, was done some time ago. At that time, the idea of providing modelling tools for young children was very new. Since then, others have taken up the idea. However, it may be claimed, at least, the results of this (early) research are in substantial agreement with the results that others have found since.

It is also the case that the relevance of the research has not diminished with time as much as one might a-priori have expected. Modelling has still not found a secure place in the curriculum over this time, therefore the results of a study such as this, of the basic possibilities and difficulties offered by one modelling tool (now one of several) are still pertinent to the design of curriculum tasks and opportunities.

REFERENCES

Adamson, R., Lowe, S., Hoyles, C., Tholander, J. and Noss, R. (2002), *Collaborative change to rules of the game: from player to system rules*. [Online]. Available at: http://www.ioe.ac.uk/playground/research/papers.htm. Last accessed 06/05/2006.

Black, M. (1962), *Models and metaphors: studies in language and philosophy*. Ithaca, N.Y.: Cornell University Press.

Bliss, J. (1994a), 'From mental models to modelling'. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn and C. Tompsett (eds), *Learning with artificial worlds: computer-based modelling in the curriculum* (pp. 27-32). London: The Falmer Press.

Bliss, J. (1994b), 'Knowledge acquisition as an active process'. In R. Lewis and P. Mendelsohn (eds), *Lessons from learning: proceedings of the IFIP TC3/WG3.3 working conference on lessons from learning* (pp. 23-37), Archamps, France, September 1993. Amsterdam: North-Holland.

Bliss, J. (1994c), 'Reasoning with a semi-quantitative tool'. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn and C. Tompsett (eds), *Learning with artificial worlds: computer-based modelling in the curriculum* (pp. 128-141). London: The Falmer Press.

Bliss, J. (1995), 'Piaget and after: the case of learning science'. *Studies in Science Education,* 25*,* 139-172.

Bliss, J. (1996), 'Externalizing thinking through modeling: ESRC tools for exploratory learning research program'. In S. Vosniadou, E. d. Corte, R. Glaser and H. Mandl (eds), *International perspectives on the design of technology-supported learning environments* (pp. 25-40). Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc., Publishers.

Bliss, J., Monk, M. and Ogborn, J. (1983), *Qualitative data analysis for educational research: a guide to uses of systemic networks*. London: Croom Helm.

Bliss, J., Ogborn, J., Boohan, R., Briggs, J., Brosnan, T., Brough, D., Mellar, H., Miller, R., Nash, C., Rodgers, C. and Sakonidis, B. (1992), 'Reasoning supported by computational tools'. *Computers & Education,* 18 (1-3)*,* 1-9.

Boohan, R. (1992), 'WorldMaker: an object-based approach to computer modelling'. In *Proceedings of the European conference about information technology in education: a critical insight* (Vol. 1, pp. 30-39), Barcelona, Spain, November 1992. Barcelona: University of Barcelona.

Boohan, R. (1994), 'Creating worlds from objects and events'. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn and C. Tompsett (eds), *Learning with artificial worlds: computer-based modelling in the curriculum* (pp. 171-179). London: The Falmer Press.

Boohan, R. (1995a), 'Children and computer modelling: making worlds with WorldMaker'. In J. D. Tinsley and T. J. van Weert (eds), *World conference on computers in education VI: WCCE '95, liberating the learner: proceedings of the sixth IFIP world conference on computers in education* (pp. 975-985), Birmingham, England, July 1995. London: Chapman & Hall.

Boohan, R. (1995b), *Why is a rumour like an infectious disease? – computer modelling with WorldMaker*. [Online]. Available at: http://www.richard-boohan.org/publications/. Last accessed 13/05/2006.

Boohan, R. (1997), 'Computer modelling and dynamic processes in science education'. In *Exploring models and modelling in science and technology education: contributions from the MISTRE group* (pp. 126-144). Reading: The New Bulmershe Papers, The University of Reading.

Boohan, R. (2002), 'Learning with models, learning about models'. In S. Amos and R. Boohan (eds), *Aspects of teaching secondary science: perspectives on practice* (pp. 117-129). London: RoutledgeFarmer.

Boohan, R. and Maragoudaki, E. (1997), *Computer worlds and the real world: exploring children's understanding with WorldMaker*. Paper presented at the

ESERA conference, Rome, Italy, September 1997. [Online]. Available at: http://www.richard-boohan.org/publications/. Last accessed 02/05/2006.

Boohan, R., Ogborn, J. and Wright, S. (1993), *WorldMaker: software and teachers' guide*. Unpublished.

Bruner, J. S. (1966), *Toward a theory of instruction*. Cambridge, Mass.: Belknap Press of Harvard University.

Buckley, B. C., Boulter, C. J. and Gilbert, J. K. (1997), 'Towards a typology of models for science education'. In *Exploring models and modelling in science and technology education: contributions from the MISTRE group* (pp. 90-105). Reading: The New Bulmershe Papers, The University of Reading.

Carey, S. and Smith, C. (1993), 'On understanding the nature of scientific knowledge'. *Educational Psychologist,* 28 (3), 235-251.

Carmichael, P. (2000), 'Computers and the development of mental models'. In J. K. Gilbert and C. J. Boulter (eds), *Developing models in science education* (pp. 177-189). Dordrecht: Kluwer Academic Publishers.

Cherry, G., Ioannidou, A., Rader, C., Brand, C. and Repenning, A. (1999), *Simulations for lifelong learning*. [Online]. Available at: http://www.cs.colorado.edu/~ralex/papers/. Last accessed 06/05/2006.

CITE (2001a), *CITE – WorldMaker* [Home of WorldMaker developed at CITE, Faculty of Education, University of Hong Kong]. [Online]. Available at: http://worldmaker.cite.hku.hk/worldmaker/pages/. Last accessed 14/05/2006.

CITE (2001b), *WorldMaker 2000 – User Manual*. [Online]. Available at: http://worldmaker.cite.hku.hk/worldmaker/manual/manual_english.pdf. Last accessed 08/05/2006.

Colella, V., Klopfer, E. and Resnick, M. (2001), *Adventures in modeling: exploring complex, dynamic systems with StarLogo*. New York: Teachers College Press.

Craig, B. S. (1997), *AGES: Agentsheets genetic evolutionary simulations*. [Online]. M.S. Thesis, University of Colorado. Available at: http://www.cs.colorado.edu/~ralex/papers/. Last accessed 01/05/2006.

Crawford, B. A. and Cullin, M. J. (2004), 'Supporting prospective teachers' conceptions of modelling in science'. *International Journal of Science Education,* 26 (11)*,* 1379-1401.

Cypher, A. and Smith, D. C. (1995), *KidSim: end user programming of simulations*. [Online]. Available at:http://www.acypher.com/Publications/CHI95/KidSimCHI.html. Last accessed 06/05/2006.

de Kleer, J. and Brown, J. S. (1983), 'Assumptions and ambiguities in mechanistic mental models'. In D. Gentner and A. L. Stevens (eds), *Mental models* (pp. 155-190). Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc., Publishers.

DES (1991), *Geography in the National Curriculum (England)*. London: HMSO.

DES/Welsh Office (1989a), *Mathematics in the National Curriculum*. London: HMSO.

DES/Welsh Office (1989b), *Science in the National Curriculum*. London: HMSO.

DES/Welsh Office (1990), *Technology in the National Curriculum*. London: HMSO.

DfEE/QCA (1999a), *The National Curriculum: information and communication technology (key stages 1-4)*. London: HMSO, QCA.

DfEE/QCA (1999b), *The National Curriculum: science (key stages 1-4)*. London: HMSO, QCA.

Dimitracopoulou, A., Komis, V., Apostolopoulos, P. and Politis, P. (1999), 'Design principles of a new modelling environment for young students, supporting various types of reasoning and interdisciplinary approaches'. In S. Lajoie and M. Vivet (eds), *Artificial intelligence in education, open learning environments: new computational technologies to support learning, exploration and collaboration* (pp. 109-120). Amsterdam: IOS Press.

Dorn, W. S. (1975), 'Simulation versus models: which one and when?' *Journal of Research in Science Teaching,* 12 (4)*,* 371-377.

Dreyfus, H. and Dreyfus, S. (1989), 'Why computers may never think like people'. In T. Forester (ed.), *Computers in the human context: information technology, productivity and people* (pp. 125-143). Oxford: Basil Blackwell Ltd.

Duit, R. (1991), 'On the role of analogies and metaphors in learning science'. *Science Education,* 75 (6)*,* 649-672.

Duit, R. and Glynn, S. (1996), 'Mental modelling'. In G. Welford, J. Osborne and P. Scott (eds), *Research in science education in Europe: current issues and themes* (pp. 166-176). London: The Falmer Press.

Duschl, R. A., Schweingruber, H. A., Shouse, A. W., Committee on Science Learning and Kindergarten through Eighth Grade (2007), *Taking science to school: learning and teaching science in grades K-8*. Washington, D.C.: National Academic Press.

Fishwick, P. A. (2000), *On the aesthetics of programming and modeling: Part 1: evolving program to model*, DRAFT 0.9. [Online]. Available at: http://www.cise. ufl.edu/~fishwick/tr/00/paper1.pdf. Last accessed 03/05/2006.

France, B. (2000), 'The role of models in biotechnology education: an analysis of teaching models'. In J. K. Gilbert and C. J. Boulter (eds), *Developing models in science education* (pp. 271-287). Dordrecht: Kluwer Academic Publishers.

Frederiksen, J. R. and White, B. Y. (2000), *Sources of difficulty in students' understanding causal models for physical systems*. Paper presented at a symposium on complex causality and conceptual change at the annual meeting of the American Educational Research Association, New Orleans, US, April 2000. [Online]. Available at: http://learnweb.harvard.edu/ComplexCausality/papers/. Last accessed 02/05/2006.

Gentner, D., Rattermann, M. J. and Forbus, K. D. (1993), 'The roles of similarity in transfer: separating retrievability from inferential soundness'. *Cognitive Psychology,* 25*,* 524-575.

Giere, R. N., Bickle, J. and Mauldin, R. F. (2006), *Understanding scientific reasoning*. (5th ed.). Belmont, CA: Thomson/Wadsworth.

Gilbert, J. K. and Boulter, C. J. (1998), 'Learning science through models and modelling'. In B. J. Fraser and K. G. Tobin (eds), *International handbook of science education* (Vol. 1, pp. 53-66). Dordrecht: Kluwer Academic Publishers.

Gilbert, J. K. and Osborne, R. J. (1980), 'The use of models in science and science teaching'. *European Journal of Science Education,* 2 (1)*,* 3-13.

Gilbert, S. W. (1991), 'Model building and a definition of science'. *Journal of Research in Science Teaching,* 28 (1)*,* 73-79.

Giordan, A. (1991), 'The importance of modelling in the teaching and popularization of science'. *Impact of Science on Society,* 164*,* 321-338.

Glynn, S. M., Britton, B. K., Semrud-Clikeman, M. and Muth, K. D. (1989), 'Analogical reasoning and problem solving in science textbooks'. In J. A. Glover, R. R. Ronning and C. R. Reynolds (eds), *Handbook of creativity* (pp. 383-398). New York: Plenum Press.

Gobert, J. D. and Pallant, A. (2004), 'Fosternig students' epistemologies of models via authentic model-based tasks'. *Journal of Science Education and Technology,* 13 (1)*,* 7-22.

Grosslight, L., Unger, C., Jay, E. and Smith, C. L. (1991), 'Understanding models and their use in science: conceptions of middle and high school students and experts'. *Journal of Research in Science Teaching,* 28 (9)*,* 799-822.

Hansen, J. A., Barnett, M., MaKinster, J. G. and Keating, T. (2004), 'The impact of three-dimensional computational modeling on student understanding of astronomical concepts: a quantitative analysis'. *International Journal of Science Education,* 26 (11)*,* 1365-1378.

Hodson, D. (1993), 'Re-thinking old ways: towards a more critical approach to practical work in school science'. *Studies in Science Education,* 22*,* 85-142.

Hoyles, C., Noss, R., Adamson, R. and Lowe, S. (2001), *Programming rules: what do children understand?* [Online]. Available at: http://www.ioe.ac.uk/playground /research/papers.htm. Last accessed 08/05/2006.

Ioannidou, A., Repenning, A. and Zola, J. (1998), *Posterboards or Java applets?* [Online]. Available at: http://www.cs.colorado.edu/~ralex/papers/. Last accessed 05/05/2006.

Johnson-Laird, P. N. (1983), *Mental models: towards a cognitive science of language, inference, and consciousness*. Cambridge: Cambridge University Press.

Justi, R. S. and Gilbert, J. K. (2002), 'Modelling, teachers' views on the nature of modelling, and implications for the education of modellers'. *International Journal of Science Education,* 24 (4)*,* 369-387.

Kahn, K. (2001a), 'Generalizing by removing detail: how any program can be created by working with examples'. In H. Lieberman (ed.), *Your wish is my command: programming by example* (pp. 21-44). San Francisco: Morgan Kaufmann Publishers.

Kahn, K. (2001b), *ToonTalk and Logo*. [Online]. New York, Logo Foundation. Available at: http://el.media.mit.edu/logo-foundation/pubs/papers/. Last accessed 06/05/2006.

Kahn, K. (2004), *ToonTalk – steps towards ideal computer-based learning environments*. [Online]. Available at: http://www.lkl.ac.uk/kscope/weblabs/ papers.htm. Last accessed 06/05/2006.

Kay, A. (n.d.), *Squeak Etoys authoring & media*. [Online]. Available at: http://www. squeakland.org/pdf/etoys_n_authoring.pdf. Last accessed 13/05/2006.

Kelleher, C. and Pausch, R. (2003), *Lowering the barriers to programming: a survey of programming environments and languages for novice programmers*. [Online].

Available at: http://reports-archive.adm.cs.cmu.edu/anon/anon/2003/abstracts/03-137.html. Last accessed 06/05/2006.

Kelly, A. V. (1984), *Microcomputers and the curriculum*. London: Harper & Row.

Kindborg, M. (2003), *Concurrent comics – programming of social agents by children*. [Online]. PhD Thesis, Linköpings Universitet, Linköping, Sweden. Available at: http://www.ida.liu.se/~mikki/comics/. Last accessed 01/05/2006.

Klopfer, E., Colella, V. and Resnick, M. (2002), 'New paths on a StarLogo adventure'. *Computers & Graphics,* 26*,* 615-622.

Law, N. (2004), 'Scaffolding scientific conceptualizations: from iconic modelling & simulations to collaborative gaming'. In M. Kankaanranta, P. Neittaanmäki and P. Häkkinen (eds), *Elektronisten pelien maailmoja* (in Finnish) (pp. 239-256). Jyväskylä: Institute for Educational Research & Agora Center, University of Jyväskylä.

Law, N. and Lee, Y. (2004), 'Using an iconic modelling tool to support the learning of genetics concepts'. *Journal of Biological Education,* 38 (3)*,* 118-141.

Law, N. and Tam, E. W. C. (1998), 'WORLDMAKER (HK) – An iconic modelling tool for children to explore complex behaviour'. In T. W. Chan, A. Collins and J. Lin (eds), *Global education on the net: proceedings of the sixth international conference on computers in education* (Vol. 2, pp. 466-472), Beijing, China, October 1998. Beijing: China Higher Education Press and Springer-Verlag.

Louca, L. and Constantinou, C. P. (2002), *The use of computer-based microworlds for developing modeling skills in physical science: an example from light*. [Online]. Available at: http://www.stagecast.com/cgi-bin/templator.cgi?PAGE=Corporate/presentations/PRESENTATIONS. Last accessed 06/05/2006.

Louca, L., Druin, A., Hammer, D. and Dreher, D. (2003), *Students' collaborative use of computer-based programming tools in science: a descriptive study*. [Online]. Available at: http://www.stagecast.com/cgi-bin/templator.cgi?PAGE=Corporate/presentations/PRESENTATIONS. Last accessed 05/05/2006.

Mandinach, E. B. (1989), 'Model-building and the use of computer simulation of dynamic systems'. *Journal of Educational Computing Research,* 5 (2)*,* 221-243.

Maragoudaki, E. (1991), *Looking for the researchers' thinking when they carry out researches into children's ideas about the particulate nature of matter.* Unpublished MA Dissertation, Institute of Education, University of London, London.

Maragoudaki, E. (1993), 'Looking for children's modelling abilities with particular interest in children's use of formal rules'. In P. L. Lijnse (ed.), *European research in science education: proceedings of the first Ph.D. Summerschool* (pp. 195-200). Utrecht: Cd-b Press, Centrum voor b-Didaktiek.

Maragoudaki, E., Boohan, R. and Ogborn, J. (1997), *Computer models, rules and behaviours: children's understanding of structures*. Paper presented at the 7th European Conference for Research on Learning and Instruction, Athens, Greece, August 1997. [Online]. Available at: http://www.richard-boohan.org/ publications/. Last accessed 02/05/2006.

MARS (2004), *Welcome to MARS!* [Homepage of the Model Assisted Reasoning in Science]. [Online]. Available at: http://www.lrdc.pitt.edu/mars/index.html. Last accessed 14/05/2006.

Martin, C. K. (1999), *Teaching basic computer science concepts through programming by example: a study teaching middle school students computer science using Stagecast Creator*. [Online]. Available at: http://teacherbridge.cs. vt.edu/public/users/isenhour/demos/NRHD+demo/Creator.pdf. Last accessed 08/05/2006.

Marx, G. (1984), *Games nature plays*. Budapest: Roland Eötvös University.

Mellar, H. (1990), 'Creating alternative realities: computers, modelling and curriculum change'. In P. Dowling and R. Noss (eds), *Mathematics versus the National Curriculum* (pp. 176-191). London: The Falmer Press.

Mellar, H. and Bliss, J. (1994), 'Introduction: modelling and education'. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn and C. Tompsett (eds), *Learning with artificial worlds: computer-based modelling in the curriculum* (pp. 1-7). London: The Falmer Press.

Millar, R. and Driver, R. (1987), 'Beyond processes'. *Studies in Science Education,* 14*,* 33-62.

Miller, R., Ogborn, J., Briggs, J., Brough, D., Bliss, J., Boohan, R., Brosnan, T., Mellar, H. and Sakonidis, B. (1993), 'Educational tools for computational modelling'. *Computers & Education,* 21 (3)*,* 205-261.

Miller, R. S., Ogborn, J. M., Turner, J., Briggs, J. H. and Brough, D. R. (1991), 'Towards a tool to support semi-quantitative modelling'. In R. Lewis and S. Otsuki (eds), *Advanced research on computers in education: proceedings of the IFIP TC3 international conference on advanced research on computers in education,* (pp. 161-166), Tokyo, Japan, July 1990. Amsterdam: North-Holland.

Millwood, R. and Stevens, M. (1990), 'What is the modelling curriculum?' *Computers & Education,* 15 (1-3)*,* 249-254.

Morgado, L., Cruz, M. G. B. and Kahn, K. (2001), *Working in ToonTalk with 4-and 5-year olds*. Paper presented at the Playground International Seminar, Porto, Portugal, April 2001. [Online]. Available at: http://www.cnotinfor.pt/playground_seminar/proceedings/pdf/leonel%20morgado.pdf. Last accessed 07/05/2006.

Mousoulides, N. and Philippou, G. (2005), *Developing new representations and mathematical models in a computational learning environment*. Paper presented at the fourth Congress of the European Society for Research in Mathematics Education, Sant Feliu de Guíxols, Spain, February 2005. [Online]. Available at: http://cerme4.crm.es/Papers%20definitius/9/wg9listofpapers.htm. Last accessed 07/05/2006.

Murphy, C. (2003), *Literature review in primary science and ICT*. Bristol: NESTA Futurelab.

Myers, B. A. (1998), *Natural programming: project overview and proposal*. [Online]. Available at: http://reports-archive.adm.cs.cmu.edu/anon/1998/CMU-CS-98-101.html. Last accessed 05/05/2006.

Noss, R., Hoyles, C., Gurtner, J.-L., Adamson, R. and Lowe, S. (2002), 'Face-to-face and online collaboration: appreciating rules and adding complexity'. *International Journal of Continuing Engineering Education and Lifelong Learning,* 12 (5-6)*,* 521-539.

Ogborn, J. (1990), 'A future for modelling in science education'. *Journal of Computer Assisted Learning,* 6*,* 103-112.

Ogborn, J. (1992), 'Modelling with the computer at all ages'. *Portugaliae Physica,* 21 (3-4)*,* 93-114.

Ogborn, J. (1994), 'Overview: the nature of modelling'. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn and C. Tompsett (eds), *Learning with artificial worlds: computer-based modelling in the curriculum* (pp. 11-15). London: The Falmer Press.

Ogborn, J. (1998), 'Cognitive development and qualitative modelling'. *Journal of Computer Assisted Learning,* 14*,* 292-307.

Ogborn, J. (1999), 'Modeling clay for thinking and learning'. In W. Feurzeig and N. Roberts (eds), *Modeling and simulation in science and mathematics education* (pp. 5-37). New York: Springer-Verlag.

Osborne, J. and Hennessy, S. (2003), *Literature review in science education and the role of ICT: promise, problems and future directions*. Bristol: NESTA Futurelab.

Papadouris, N. and Constantinou, C. P. (n.d.), *Systematic analysis of the potential contribution of communication and information tools to the design and development of research-based science curriculum*. [Online]. Available at: http://cblis.utc.sk/cblis-cd-old/2001/text/pdf/a6.pdf. Last accessed 06/05/2006.

Penner, D. E., Giles, N. D., Lehrer, R. and Schauble, L. (1997), 'Building functional models: designing an elbow'. *Journal of Research in Science Teaching,* 34 (2)*,* 125-143.

Perkins, D. N. and Grotzer, T. A. (2001), *Models and moves: the role of causal and epistemic complexity in students' understanding of science*. [Online]. Available at: http://pzweb.harvard.edu/Research/UCPpapers/CausalityAERA.pdf. Last accessed 02/05/2006.

Piaget, J. (1932), *The moral judgment of the child*. London: Routledge & Kegan Paul Ltd.

QCA (2000a), *Schemes of work: ICT at key stage 3*. [Online]. Available at: http:// www.standards.dfes.gov.uk/schemes2/secondary_ICT/?view=Download. Last accessed 20/03/2006.

QCA (2000b), *Schemes of work: ICT at key stages 1 and 2*. [Online]. Available at: http://www.standards.dfes.gov.uk/schemes2/it/?view=Download. Last accessed 20/03/2006.

Rader, C., Brand, C. and Lewis, C. (1997), *Degrees of comprehension: children's understanding of a visual programming environment*. [Online]. Available at: http://www.sigchi.org/chi97/proceedings/paper/car.htm. Last accessed 06/05/2006.

Rader, C., Cherry, G., Brand, C., Repenning, A. and Lewis, C. (1998), *Principles to scaffold mixed textual and iconic end-user programming languages*. [Online]. Available at: http://www.cs.colorado.edu/~ralex/papers/. Last accessed 03/05/2006.

Raghavan, K. and Glaser, R. (1995), 'Model-based analysis and reasoning in science: the MARS curriculum'. *Science Education,* 79 (1)*,* 37-61.

Raghavan, K., Sartoris, M. L. and Zimmerman, C. (2002), *Impact of model-centered instruction on student learning*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, April

2002. [Online]. Available at: www.pitt.edu/~marsci/MARSresults.htm. Last accessed 02/05/2006.

Repenning, A. (1993), *Agentsheets: a tool for building domain-oriented dynamic, visual environments*. [Online]. Ph.D. Dissertation, University of Colorado, Boulder. Available at: http://www.cs.colorado.edu/~ralex/papers/. Last accessed 01/05/2006.

Repenning, A., Ioannidou, A. and Zola, J. (2000), 'AgentSheets: end-user programmable simulations'. [Online]. *Journal of Artificial Societies and Social Simulation*, 3 (3). Available at: http://jasss.soc.surrey.ac.uk/3/3/forum/1.html. Last accessed 06/05/2006.

Resnick, M. (1995), 'New paradigms for computing, new paradigms for thinking'. In A. A. diSessa, C. Hoyles and R. Noss (eds), *Computers and exploratory learning* (pp. 31-43). Berlin: Springer in cooperation with NATO Scientific Affairs Division.

Resnick, M. (1999), 'Decentralized modeling and decentralized Thinking'. In W. Feurzeig and N. Roberts (eds), *Modeling and simulation in science and mathematics education* (pp. 114-137). New York: Springer-Verlag.

Resnick, M., Bruckman, A. and Martin, F. (1999), 'Constructional design: creating new construction kits for kids'. In A. Druin (ed.), *The design of children's technology* (pp. 149-168). San Francisco, CA: Morgan Kaufmann Publishers, Inc.

Richmond, B. (1987), *An academic user's guide to STELLA*. New Hampshire: High Performance Systems Inc.

Sampaio, F. F. (1996), *LinkIt: deign, development and testing of a semi-quantitative computer modelling tool.* Unpublished PhD Thesis, Institute of Education, University of London, London.

Scaife, J. and Wellington, J. (1993), *Information technology in science and technology education*. Buckingham: Open University Press.

Schwarz, C. and White, B. (1998), *Fostering middle school students' understanding of scientific modeling*. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA, April 1998. [Online]. Available at: http://eric.ed.gov/ERICDocs/data/ericdocs2/content_storage_01/0000000b/80/11/1f/17.pdf. Last accessed 20/03/2006.

Schwarz, C. V. and White, B. Y. (2005), 'Metamodeling knowledge: developing students' understanding of scientific modeling'. *Cognition and Instruction,* 23 (2)*,* 165-205.

Smith, C., Snir, J. and Grosslight, L. (1992), 'Using conceptual models to facilitate conceptual change: the case of weight-density differentiation'. *Cognition and Instruction,* 9*,* 221-283.

Smith, D. C. and Cypher, A. (1999), 'Making programming easier for children'. In A. Druin (ed.), *The design of children's technology* (pp. 201-221). San Francisco, CA: Morgan Kaufman Publishers, Inc.

Smith, D. C., Cypher, A. and Spohrer, J. (1994), 'KidSim: programming agents without a programming language'. *Communications of the ACM,* 37 (7)*,* 54-67.

Smith, D. C., Cypher, A. and Tesler, L. (2000), 'Novice programming comes of age'. *Communications of the ACM,* 43 (3)*,* 75-81.

Snir, J., Smith, C. and Grosslight, L. (1995), 'Conceptually enhanced simulations: a computer tool for science teaching'. In D. N. Perkins, J. L. Schwartz, M. M. West and M. S. Wiske (eds), *Software goes to school: teaching for understanding with new technologies* (pp. 106-129). New York: Oxford University Press.

Spitulnik, M. W., Krajcik, J. and Soloway, E. (1999), 'Construction of models to promote scientific understanding'. In W. Feurzeig and N. Roberts (eds), *Modeling and simulation in science and mathematics education* (pp. 70-94). New York: Springer-Verlag.

Squeak (n.d.), *Welcome to Squeakland* [Homepage of Squeak]. [Online]. Available at: http://www.squeakland.org. Last accessed 14/05/2006.

Stewart, J., Hafner, R., Johnson, S. and Finkel, E. (1992), 'Science as model building: computers and high school genetics'. *Educational Psychologist,* 27 (3)*,* 317-336.

Stratford, S. J., Krajcik, J. and Soloway, E. (1998), 'Secondary students' dynamic modeling processes: analyzing, reasoning about, synthesizing and testing models of stream ecosystems'. *Journal of Science Education and Technology,* 7 (3)*,* 215-234.

Stylianidou, F., Boohan, R. and Ogborn, J. (2005), 'Science teachers' transformations of the use of computer modeling in the classroom: using research to inform training'. *Science Education,* 89 (1)*,* 56-70.

Teodoro, V. D. (2002), *Modellus: learning physics with mathematical modelling.* Unpublished PhD Thesis, Universidade Nova de Lisboa, Lisboa.

Webb, M. (1992), 'Learning by building rule-based models'. *Computers & Education,* 18 (1-3)*,* 89-100.

Webb, M. E. (1994), 'Beginning computer-based modelling in primary schools'. *Computers & Education,* 22 (1-2)*,* 129-144.

Wilensky, U. and Resnick, M. (1999), 'Thinking in levels: a dynamic systems approach to making sense of the world'. *Journal of Science Education and Technology,* 8 (1)*,* 3-19.

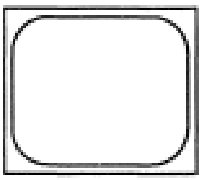
Wiser, M., Kipman, D. and Halkiadakis, L. (1988), *Can models foster conceptual change? The case of heat and temperature* (Tech. Rep. No. TR88-7). Cambridge, MA: Harvard Graduate School of Education, Educational Technology Center.

APPENDIX A

Instructions for Using WorldMaker in the Preliminary and the First Main Studies

Instructions for using WorldMaker

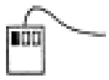
All the instructions have pictures next to them.



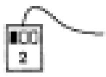
The first picture is like this. It shows where you should *look* on the screen.

The second picture looks like this. It shows what you should *do*.

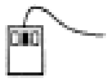
You may need to:



Click the SELECT button on the mouse.



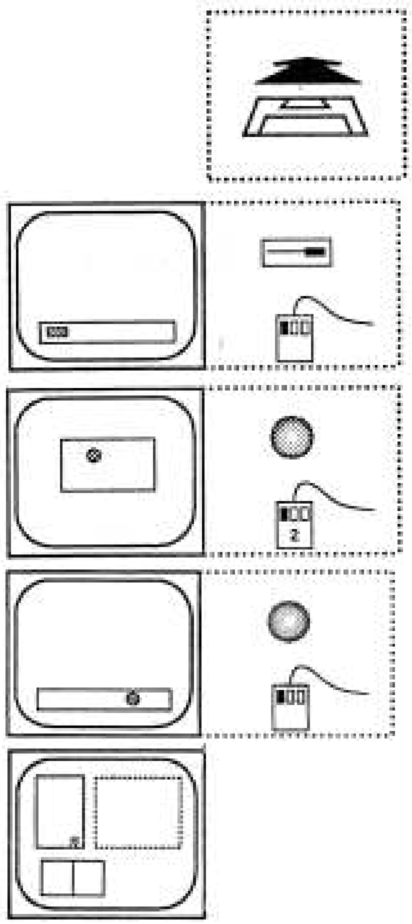
Double-click the SELECT button on the mouse.



Click the MENU button on the mouse.

Type something at the keyboard.

1 Starting up WorldMaker



Put the ‘WorldMaker’ disc in the computer.

Click on the floppy disc icon on the icon bar on the bottom left.

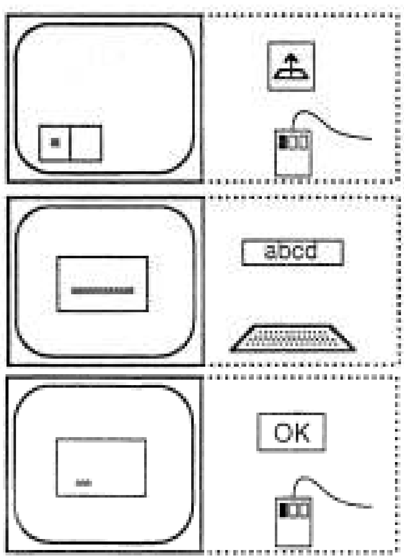
Double-click on the ‘!WorldMkr’ icon using the SELECT (left) button of the mouse.

Wait for a few seconds while it is loading. The icon should appear on the icon bar.

Click on the icon on the icon bar.

You should see three windows open up.

2 Loading a model



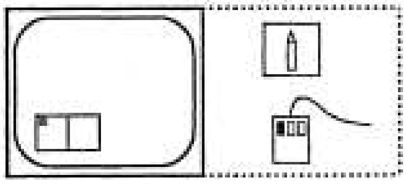
Click on the ‘load model’ icon in the ‘Tools’ window.

A dialogue box opens.

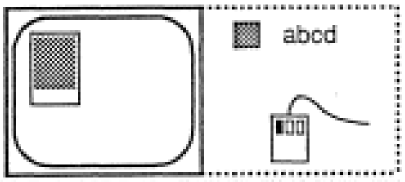
Type in the name of the model to load.

Click on ‘OK’.

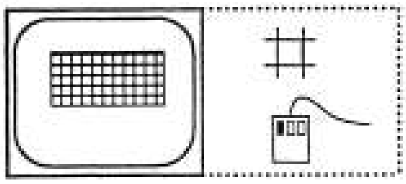
3 Plotting a filler on the grid (object or background)



Click on the 'pencil' icon in the 'Tools' window.

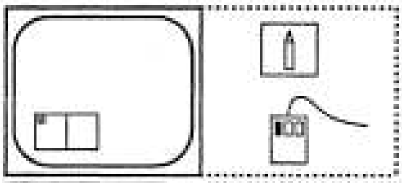


Click on a filler in the 'Fillers' window.

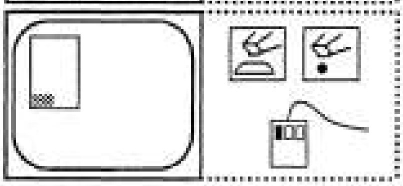


Click on a cell in the 'Grid' window.

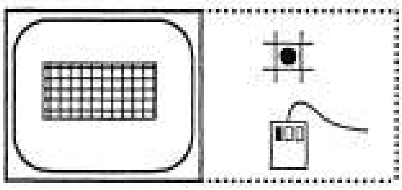
4 Removing a filler from the grid (object or background)



Click on the 'pencil' icon in the 'Tools' window.

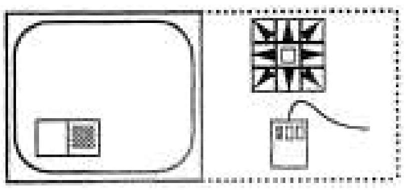


Click on the 'eraser' icon in the 'Fillers' window.



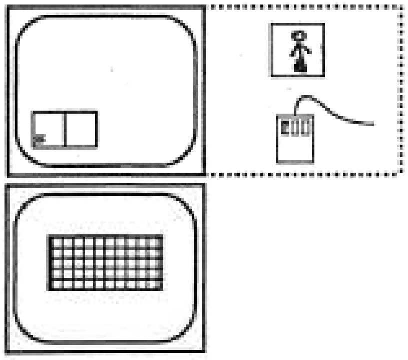
Click on the fillers you want to remove in the 'Grid' window.

5 Giving a direction to a filler



Before plotting a filler **(3)**, click on a direction in the 'Tools' window.

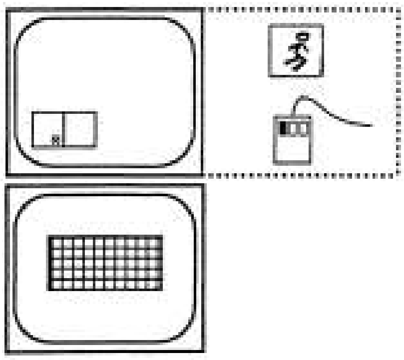
6 Stopping a model



Click on the ‘stop’ icon in the ‘Tools’ window.

When the model is not running, the lines on the grid change to red.

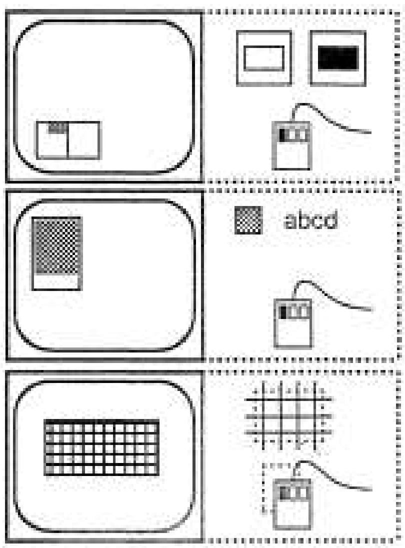
7 Running a model



Click on the ‘run’ icon in the ‘Tools’ window.

When the model is running, the lines on the grid change to black.

8 Plotting outlines or blocks of fillers

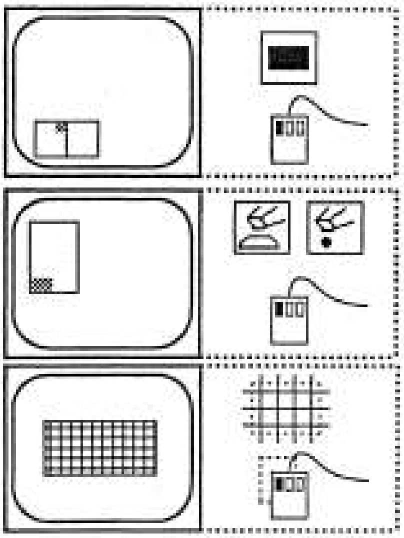


Click on the ‘outline’ or ‘block’ icon in the ‘Tools’ window.

Click on a filler in the ‘Fillers’ window.

Click on a cell in the ‘Grid’ window, but DO NOT RELEASE THE BUTTON. Drag the mouse to point to another cell. Release the button.

9 Removing blocks of fillers

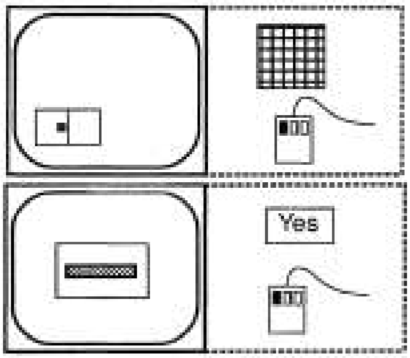


Click on the ‘block’ icon in the ‘Tools’ window.

Click on the ‘eraser’ icon in the ‘Fillers’ window.

Click on a cell in the ‘Grid’ window, but DO NOT RELEASE THE BUTTON. Drag the mouse to point to another cell. Release the button.

10 Clearing a display

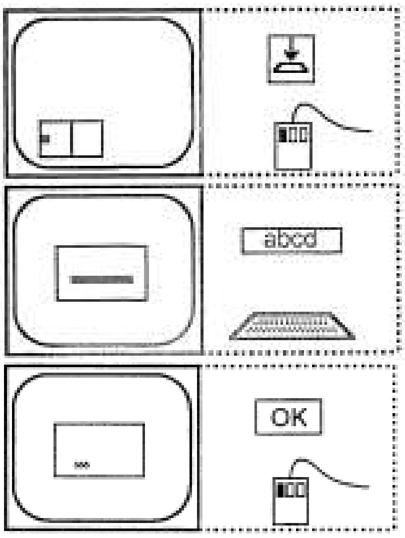


Click on the ‘clear display’ icon in the ‘Tools’ window.

A dialogue box opens.

Click on ‘Yes’.

11 Saving a model



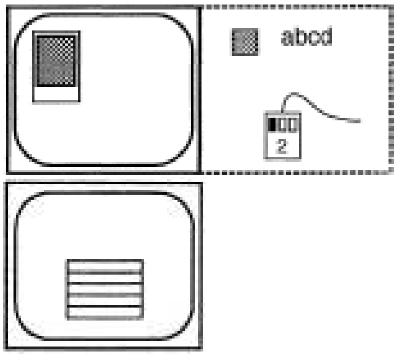
Click on the ‘save model’ icon in the ‘Tools’ window.

A dialogue box opens.

Type in the name that you want to call the model.

Click on ‘OK’.

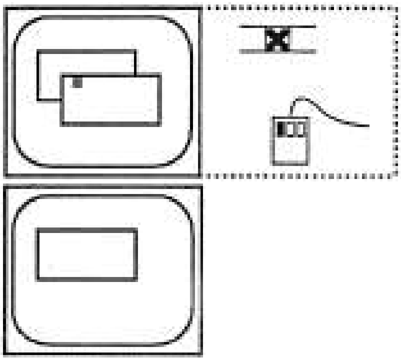
12 Opening the 'Rules' window of a filler



Double-click on the filler.

The 'Rules' window will open, showing the list of rules for that filler.

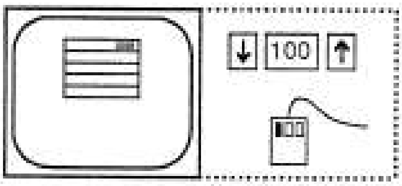
13 Closing a window



Click on the 'X' icon in the top left-hand corner of the window.

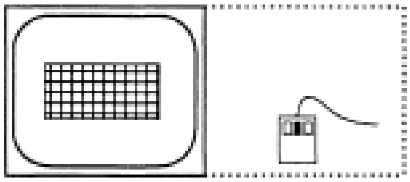
The window will close.

14 Changing the setting of a rule

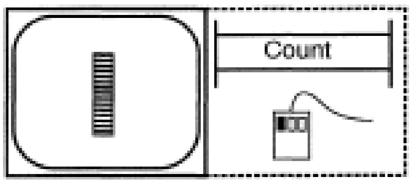


After opening the 'Rules' window **(12)**, click on the 'up' or 'down' arrow to get the setting you want.

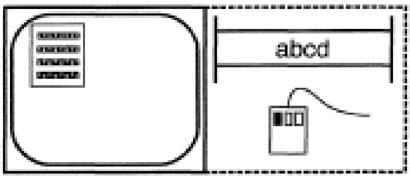
15 Using the 'Count' window



Open the 'Grid' menu, by clicking the MENU (middle) button over the 'Grid' window.

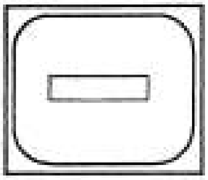


Click on the 'Count' option with the SELECT (left) button.

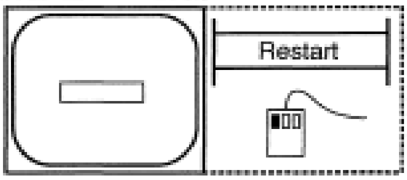


The 'Count' window opens.

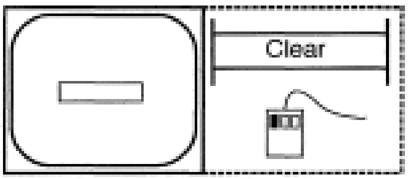
Click on one of the four grey boxes to show the name of the first filler. Keep clicking to get the filler you want.



The number of that filler at present on the grid is shown. It also shows any changes in the numbers as the model is running.

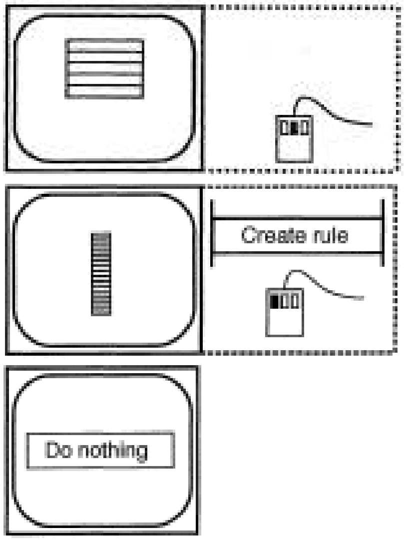


If you want to set 'Generation' to zero, click on 'Restart'.



If you want to clear all the fillers, click on 'Clear'.

16 Creating a new rule

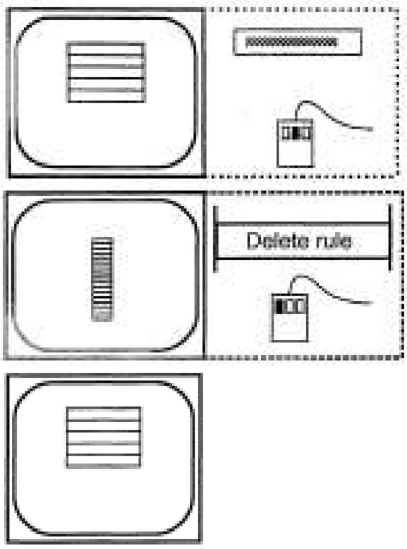


The 'Rules' window should be open **(12)**. Open the 'Rules' menu by clicking the MENU (middle) button over the 'Rules' window.

Click on the 'Create rule ...' option that you want with the SELECT button.

A new rule called 'Do nothing' will be created.

17 Deleting a rule

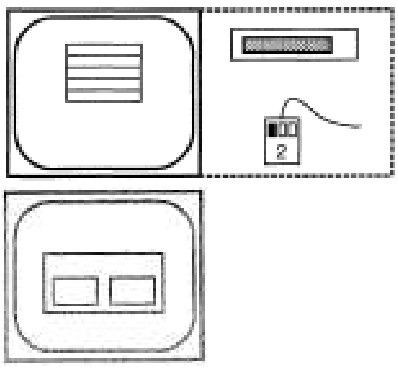


The 'Rules' window should be open **(12)**. Click the MENU (middle) button over the rule you want to delete.

Click on the 'Delete rule ...' option with the SELECT button.

The rule will be deleted.

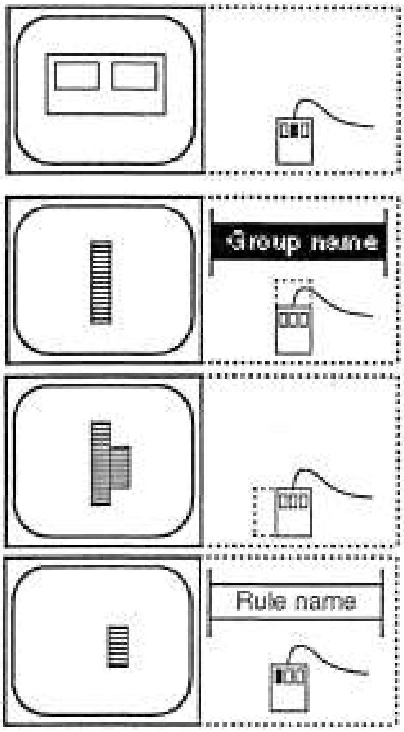
18 Opening the 'Definition' window of a rule



The 'Rules' window should be open **(12)**. Double-click on the rule.

The 'Definition' window will open.

19 Changing the definition of a rule



The ‘Definition’ window should be open **(18)**. Open the menu, by clicking the MENU button over the ‘Definition’ window.

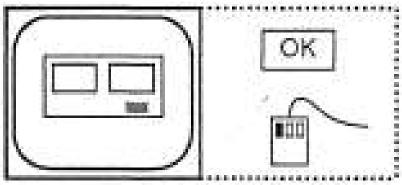
The menu shows the different groups of rules.

Move the mouse down, until the group you want is highlighted. DO NOT CLICK.

Move the mouse sideways to get a sub-menu.

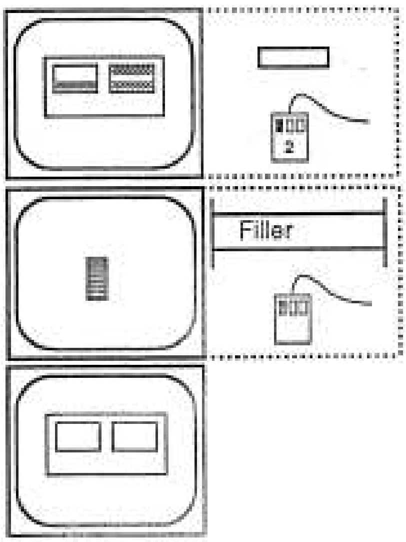
Click on the rule you want with the SELECT button.

For most rules you will also need to define other fillers **(20)**. These will appear as Ol?, O2?, Bl?,etc.



Click on ‘OK’.

20 Defining fillers in a rule



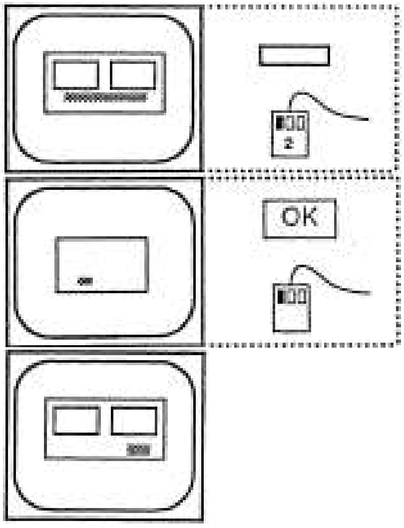
Double-click on the name of the filler you want to change.

A window showing the fillers appears.

Click on the filler you want.

The rule will be changed.

21 Changing the name of a rule



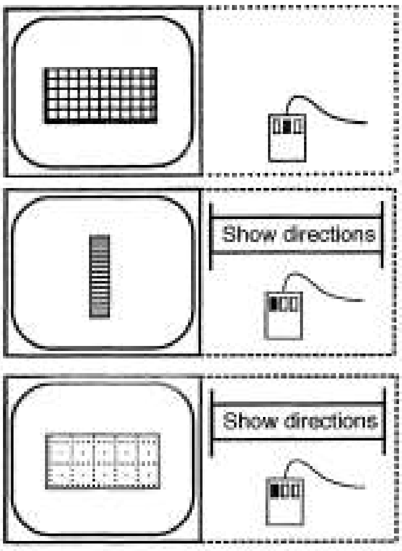
The ‘Definition’ window should be open **(18)**. Double-click on the rule name.

A dialogue box appears.

Type in the new name (you can also use the cursor keys and the DELETE key). Click on ‘OK’.

The name will be changed.

22 Showing the directions of fillers



Open the ‘Grid’ menu, by clicking the MENU button over the ‘Grid’ window.

Click on the ‘Show directions’ option with the SELECT button.

To hide the directions, click on ‘Show directions’ again.

APPENDIX B

Preliminary Study: Research Tasks

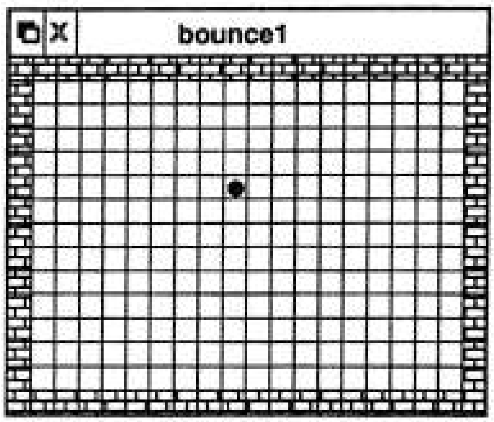
Bounce

In this task, you will be looking at a model which uses 'bouncy' balls. You can make these balls move around the screen. When they hit the wall or each other they bounce.

1. Load the model 'bouncel'. It contains two types of 'bouncy' ball called 'yellow' and 'blue'. Put a 'yellow' in one of the cells on the grid. Put a 'blue' on the grid. Try putting some more of each on the grid.

Loading a model (2)

Plotting a filler on the grid (3)



2. Now get rid of these balls.

Removing a filler from the grid (4)

3. To make balls move around on the grid, you need to give them a *direction* first. Choose a direction, then put a ball in a cell on the grid. Try different balls in different directions.

Giving a direction to a filler (5)

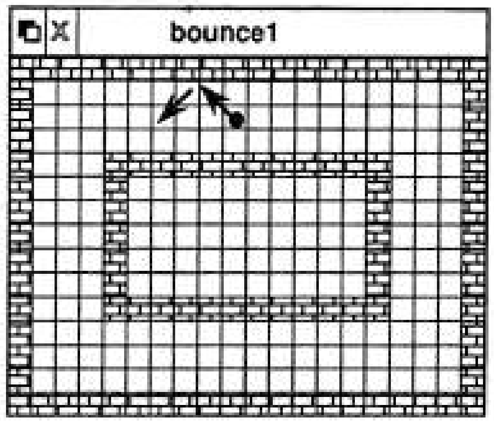
4. Now get rid of these balls. It can be difficult to do this when they are moving. It makes it easier if you *stop* the model to do this. After you have finished, set the model back to *run.*

Stopping a model (6)

Running a model (7)

5. Put some 'walls' on the grid to make a box that looks like this. You *could* use the 'pencil', but it is quicker to use the 'outline' tool. Can you make a ball bounce all the way around the inside?

Plotting outlines or blocks of fillers (8)



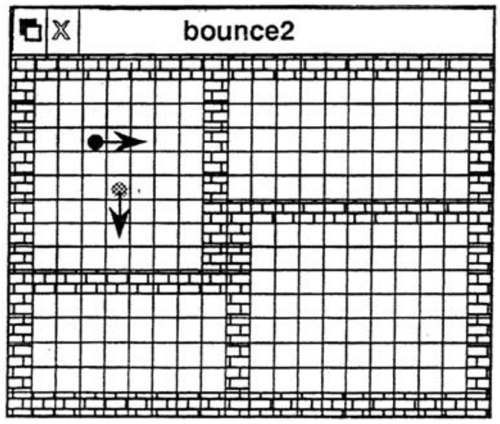
6. The next part of the task looks at different patterns in the way that balls bounce.

Load the model 'bounce2'.

Loading a model (2)

7. There are four 'boxes' that you can put the balls in. In the first box, put a yellow ball that bounces up and down, and a blue ball that bounces from side to side. Do they hit each other?

Giving a direction to a filler (5)
Plotting a filler on the grid (3)



8. Try the other boxes, with the balls bouncing in the same way. In two boxes the balls will always hit each other. In the other two you can make the balls avoid each other. Can you find out which is which?

9. For the boxes where the balls do not hit, count the numbers of cells across. Count the number of cells down. Can you see a pattern? Do this for the other two boxes.

10. Try to make some boxes of your own.

First you will need to clear the grid. You *could* use the 'pencil', but for large areas it is quicker to use the 'block' tool. If you want to clear the *whole* grid, use the 'clear display' tool.

Removing blocks of fillers (9)

Clearing a display (10)

Try making a box in which the balls never hit. Try another in which the balls always hit.

11. If you want to keep you model, you will need to *save* it.

Saving a model (11)

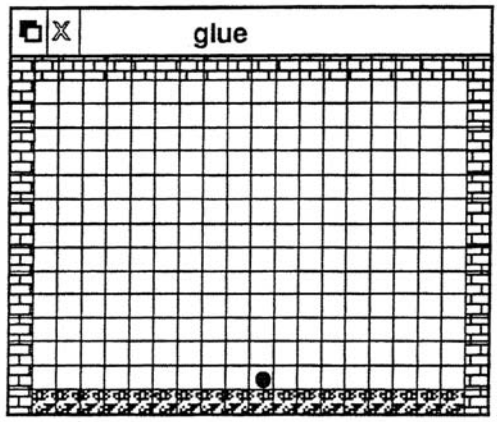
Glue

In this model, some of the fillers behave a bit like glue. You can see what shapes the glue makes when it 'sets' to a solid.

1. Load the model 'glue'. Put one of the objects 'tubel' at the bottom of the grid. Watch carefully what happens.

Loading a model (2)

Plotting a filler on the grid (3)



2. After you have seen what happens, try using 'tube2'. First get rid of 'tube1' and the 'solid', but make sure you leave the row of solid at the bottom. Put on 'tube2', and watch carefully what happens.

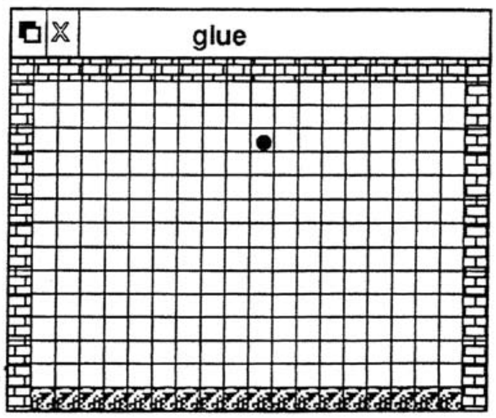
Removing a filler from the grid (4)
Removing blocks of fillers (9)

3. Can you see any differences between 'tube1' and 'tube2'?

4. Try the same thing again, but this time with the 'tubes' on the top of the grid. Do 'tubel' first, and then 'tube2'.

5. What can you see happening?

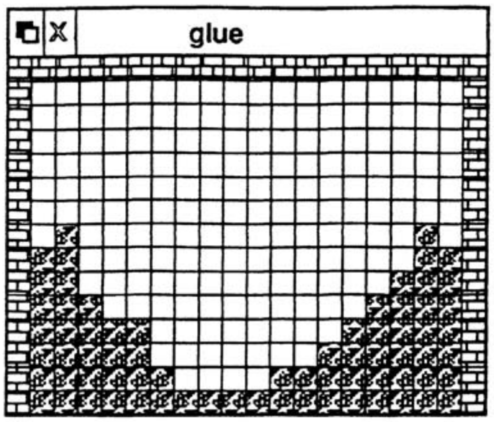
6. This may remind you a bit of a volcano. Why do you think that some volcanoes are quite flat, while others have steep sides?

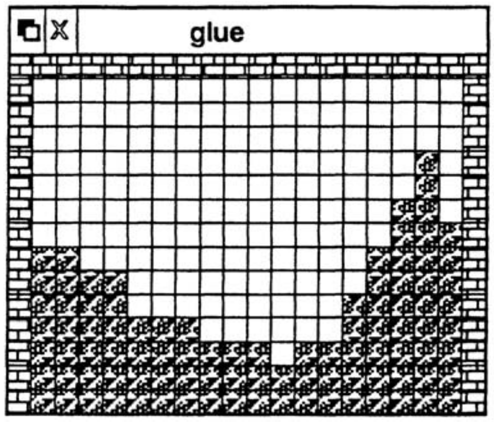


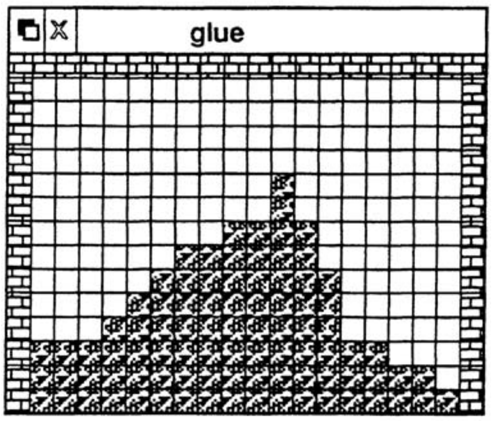
7. Here are three pictures of shapes that were made just by putting 'tubes' on the grid.

Can you work out where you could put the objects 'tubel' and 'tube2' to produce shapes like these?

Try out your ideas.





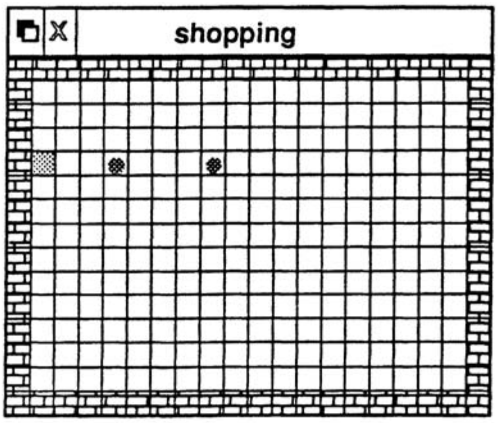


Shopping

This task looks at a model of what happens in a supermarket. Shoppers come into the supermarket, and leave at the checkout. You can control how often they come and leave.

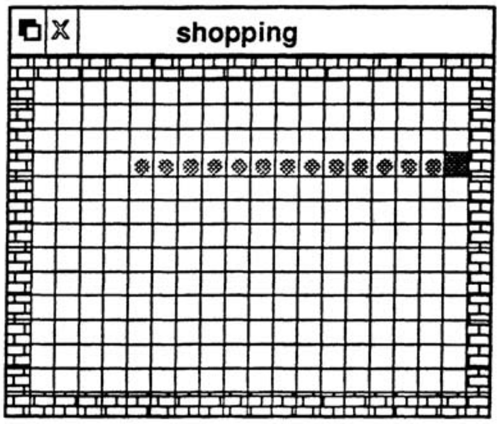
1. Load the model ‘shopping’. Put an ‘entrance’ on the grid. Watch how the shoppers appear and move across the grid. After a while, there will be a queue of shoppers.

Loading a model (2)
Plotting a filler on the grid (3)



2. Now get rid of the ‘entrance’ so that no more shoppers can come in. Put a ‘checkout’ at the other end of the line of shoppers. Watch how the shoppers disappear. After a while all the shoppers have gone.

Removing a filler form the grid (4)



3. Put the entrance back where it was. Shoppers will now appear at the entrance, and disappear at the checkout.

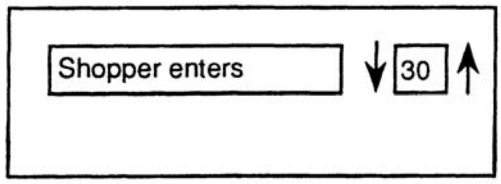
4. Watch the shoppers entering. Do they come regularly? Or do they sometimes come several at a time with pauses when none come?

5. Watch the shoppers leaving. Do they leave regularly?

6. Watch the queue. Is it always the same length? Are there times when there is no queue?

7. You can also change how often the shoppers arrive. To do this, you need to open up the 'Rules' window for 'entrance'. This shows its list of rules. In fact, 'entrance' has just one rule – 'Shopper enters'.

Opening the 'Rules' window of a filler (12)



Next to the rule is a number – the rule setting. At present it is at '30'. This rule setting controls how often the shoppers enter. So, making it bigger means that the shoppers arrive more often (the highest is 100). Making it smaller means they arrive less often (0 is the smallest which means that there are no shoppers).

Changing the setting of a rule (14)

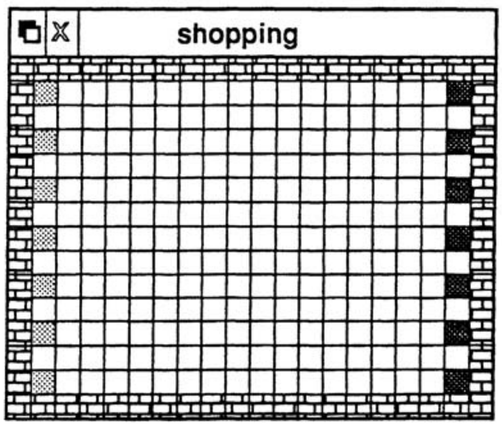
Increase the setting to '40', and close the 'Rules' window. Watch the queue again. What happens?

Closing a window (13)

8. The 'checkout' also has one rule – 'Shopper leaves'. Try increasing the setting of this rule. Watch what happens to the queue.

9. Try different settings for each of the rules. For example, try one setting very high and the other very low. Watch the queue. Can you explain what happens?

10. If you have time, you could compare different queues by setting up several entrances and checkouts on the same grid.

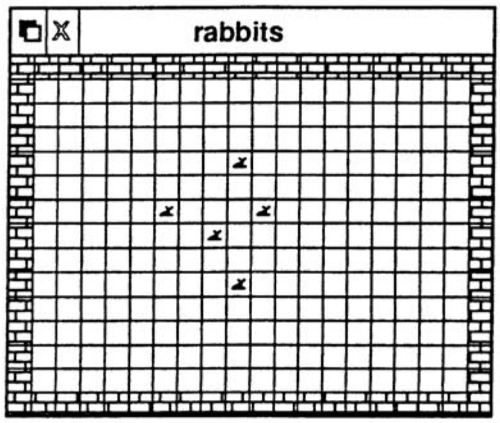


Rabbits

Rabbits breed and make more rabbits. Rabbits also die. If they did not, the world would quickly fill up with rabbits. Rabbits are also killed by other animals. These are called *predators*. For a rabbit, one predator is a fox. This model looks at populations of rabbits and foxes.

1. Load the model ‘rabbits’. Put a few ‘rabbits’ on the grid. Watch what happens to them.

Loading a model (2)
Plotting a filler on the grid (3)



2. Open the ‘Count’ window, so that you can count the number of rabbits. Do the numbers change? Roughly how many are there?

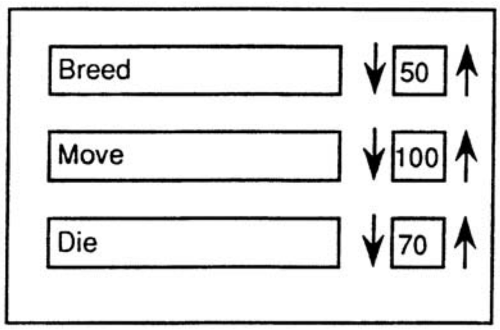
Using the ‘Count’ window (15)

3. Now fill the grid up completely with ‘rabbits’ using the ‘block’ tool. Watch what happens to them. Do the numbers change? Roughly how many are there? Compare with part 2. Are there more, less or about the same?

Plotting outlines or blocks of fillers (8)

4. Have a look at the list of rules for ‘rabbit’. There are three rules – ‘Breed’, ‘Move’ and ‘Die’.

Opening the ‘Rules’ window of a filler (12)

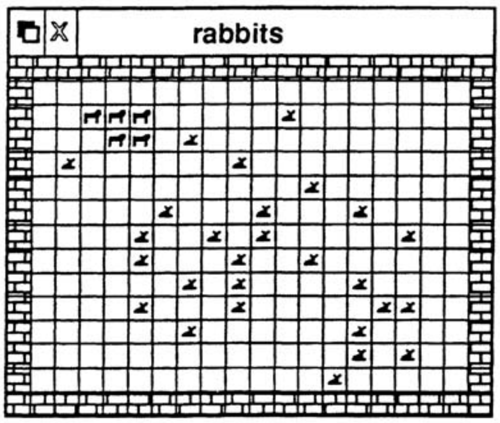


5. Try changing the settings of the rules and see what happens to the numbers of rabbits. For example, what happens if you set ‘Die’ to ‘0’? Or what happens if you increase the setting for ‘Breed’?

6. Try changing the settings until you get a population of about 30 rabbits.

Can you find more than one way of doing this?

7. Now put some foxes on the grid. What happens to the numbers of rabbit?



8. Put 20 foxes on the grid. Try changing the settings again until you get a population of about 30 rabbits.

Can you find more than one way of doing this?

Shark

In the Pacific Ocean a lot of sharks and fishes live. The sharks move around the ocean, to eat fishes, to give birth to new sharks. The fishes do more or less the same. For example, they also move around and new fishes are being born.

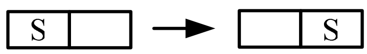
1. Load the model 'Shark'.
Put a shark on the grid.
As you see nothing happens, the shark cannot even move around the ocean.
If you want to find the reason, open the 'Rules' window for 'shark'.

Loading a model (2)
Plotting a filler on the grid (3)

Opening the 'Rules' window of a filler (12)

2. Let's call this shark Sally. Today Sally who is pregnant would like to go alone for a walk. So, you could see her jumping in the ocean, or in other words, to change positions on the grid. This means that if there are two cells and in one moment Sally is on one of them, the next moment she might be on the next to it cell.

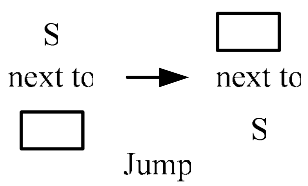
If somebody wanted to express Sally's desire more briefly he could say:



3. If you want to ask Sally to jump, you have to create a new rule.
Then, open the 'Definition' window of the 'Do nothing' rule and change each definition.
Choose the rule 'Jump' from the group 'Position' on the menu.
You should see this:

Creating a new rule (16)

Opening the 'Definition' window of a rule (18)
Changing the definition of a rule (19)



Close the 'Rules' window and see if Sally managed to move around the ocean.

4. Sally is hungry and she would like to 'meet' some fishes.
If you want to help her, put some fishes on the grid.

Plotting a filler on the grid (3)

Open the 'Rules' window for 'shark' and create a new 'Do nothing' rule.
Then, open the 'Definition' window of this rule and change its definition.
Choose the rule 'Destroys other object' from the group 'Two objects'.

Opening the 'Rules' window of a filler (12)
Creating a new rule (16)
Opening the 'Definition' window of a rule (18)
Changing the definition of a rule (19)

S next to F → S next to

Destroys other object

If you want to change the name of the rule you could do it.

Changing the name of a rule (21)

Close the 'Rules' window and watch Sally eating the fishes.

Closing a window (13)

5. Suddenly Sally started to feel strange, she realised that the new babies would born.
If you want to help her to give birth to new sharks, open the 'Rules' window for 'shark' and create a new 'Do nothing' rule.
Then, open the 'Definition' window of this rule and change its definition.
Choose the rule 'Make new' from the group 'Object only'.

Opening the 'Rules' window of a filler (12)
Creating a new rule (16)
Opening the 'Definition' window of a rule (18)
Changing the definition of a rule (19)

S next to → S next to O1?

Make new

Choose the 'Rules' window and see Sally giving birth to sharks.

Closing a window (13)

6. Clear the grid.
(It's better to stop the model before).
Put a shark and some fishes on the grid.

Clearing a display (10)
Stopping a model (6)
Plotting a filler on the grid (3)

Let's call this shark Fred. Fred, as a male, could do some and not all of the things that Sally does.
Open the 'Rules' window for 'shark', find which rule is not applied in the case of Fred and delete it.
Close the 'Rules' window and 'run' the model.

Opening the 'Rules' window of a filler (12)
Deleting a rule (17)
Closing a window (13)
Running a model (7)

7. Clear the grid and put some fishes on it.	**Clearing a display (10)**
These fishes would like to go around the ocean and give birth to new fishes.	**Plotting a filler on the grid (3)**
You could help them doing the followings:	
Open the 'Rules' window for fishes,	**Opening the 'Rules' window of a filler (12)**
create a new 'Do nothing' rule,	**Creating a new rule (16)**
and open the window of its definition.	**Opening the 'Definition' window of a rule (18)**
Change the definition choosing the rule 'Jump' from the group 'Position'.	**Changing the definition of a rule (19)**

F → ...
... ...

Jump

Then create a new 'Do nothing' rule,	**Creating a new rule (16)**
open its definition	**Opening the 'Definition' window of a rule (18)**
and change it choosing the rule 'Make new' from the group 'Object only'.	**Changing the definition of a rule (19)**

F → F
... ...

Make new

Close the 'Rules' window and see what happens.	**Closing a window (13)**

8. Unfortunately a ship passed over the fishes and spoiled poison refuse into the ocean. Some of the fishes are dying.	
Can you create a new rule for 'fish', which will say what happened in the ocean when the ship passed?	**Follow the instructions of No. 7**

F ...
→ ...
... ...

Close the 'Rules' window and see what happens.	**Closing a window (13)**

9. Put some sharks on the grid.
Plotting a filler on the grid (3)

Open the ‘Rules’ window for ‘shark’
Opening the ‘Rules’ window of a filler (12)

and delete all the rules except one which make hem move.
Deleting a rule (17)

Do the same for fishes.
Here is a list of some ‘strange’ rules which say what the fishes and sharks could do in the ocean.
Could you write down what event is being described by each rule?

S	F	→		
S	F	→	S	S
F	S	→	F	

Decide which rule you want to apply,
open the ‘Rules’ window for ‘fish’ or ‘shark’,
Opening the ‘Rules’ window of a filler (12)

create a new ‘Do nothing’ rule,
Creating a new rule (16)

open the window of its definition
Opening the ‘Definition’ window of a rule (18)

and define the fillers in the rule.
Defining fillers in a rule (20)

...   ...
... → ...
...   ...

Close the window and see what happens.
Closing a window (13)

Aliens

a. Choose a place (air, water, earth or space) where you would like a phenomenon to take place.

b. Decide which is the phenomenon that you would like to see.

c. Decide about the protagonists of the phenomenon. How many will you plot on the screen?

d. Then, decide about the nature of changes that take place during the phenomenon.
Is there any change in
→ the nature of fillers?
→ their direction?
→ their position?

e. Decide which WorldMaker rules describe the changes that take place during the phenomenon.

Look at the list of rules[1]

f. If you want to see the phenomenon, do the followings:

1. Create the objects and the backgrounds that you have already identified as protagonists[2]. Plot the fillers on the grid.

Plotting a filler on the grid (3)

2. In order to define the behaviour of each of the fillers you have to:
- Open the 'Rules' window for each of the fillers; **Opening the 'Rules' window of a filler (12)**
- Create a new 'Do nothing' rule; **Creating a new rule (16)**
- Open the definition window of the 'Do nothing' rule; **Opening the 'Definition' window of a rule (18)**
- Change the definition of the 'Do nothing' rule as you have decided (e); and **Changing the definition of a rule (19)**
- 'Run' the model. **Running a model (7)**

---

[1] A catalogue of WorldMaker rules was given to the children.

[2] The instructions for creating a filler were given orally to the children.

APPENDIX C

First Main Study: Research Tasks

Gardeners

In a garden two gardeners are growing flowers. One is growing daisies (gardener D) and the other one is growing roses (gardener R).

1. Load the game ‘Gardeners’.

   Loading a model (2)

   Put on the grid a ‘gardener D’ and a ‘gardener R’.

   Plotting a filler on the grid (3)

   a) What happens?

   ____
   ____
   ____
   ____
   ____

   b) Who managed to have most of his flowers on the grid?
   (You can open the ‘Count’ window, so that you can count the number of roses and daisies.)

   Using the ‘Count’ window (15)

   ____

2. Clear the gardeners and the flowers from the grid.

   Removing blocks of fillers (9)

   Have a look at the list of rules for ‘gardener D’. There are three rules – ‘Move’, ‘Make new daisy’, ‘Change rose to daisy’.

   Opening the ‘Rules’ window of a filler (12)

   Can you guess which will be the rules for ‘gardener R’?

   ____
   ____
   ____

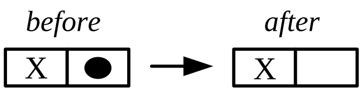
   If you want to check your answer you can have a look at the list of rules for ‘gardener R’.

   Opening the ‘Rules’ window of a filler (12)

   Close the ‘Rules’ window.

   Closing a window (13)

3. Somebody suggested to change the rule ‘Change rose to daisy’ for ‘gardener D’. The new rule that he wanted to apply is:



   a) Write down what this rule says.

   ____
   ____
   ____
   ____

b) If you apply this rule, can you guess who will manage to have most of his flowers on the grid? Explain your answer.

If you want to check your answer do the followings:
- Stop the game.
- Open the 'Definition' window of the 'Change rose to daisy' rule and
- Redefine the fillers in the rule.
- Close the 'Definition' window.

Then,
- Put a 'gardener D' and a 'gardener R' on the grid and start the game.

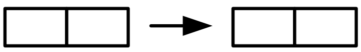
Stopping a model (6)
Opening the 'Definition' window of a rule (18)
Defining fillers in a rule (20)
Closing a window (13)

Plotting a filler on the grid (3)
Running a model (7)

4. a) If the game has to be 'fair', is there any rule for 'gardener R' that needs to be changed? Explain your answer.

b) Make a picture of the new rule.

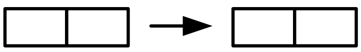
before *after*



5. If you have time, try to define a different rule.

a) Make a picture of this rule.

before *after*



b) Write down what this rule says.

Try to apply this rule following the instructions:

- Stop the game.	**Stopping a model (6)**
- Open the ‘Rules’ window of the filler.	**Opening the ‘Rules’ window of a filler (12)**
- Create a new ‘Do nothing’ rule.	**Creating a new rule (16)**
- Open the ‘Definition’ window of the ‘Do nothing’ rule.	**Opening the ‘Definition’ window of a rule (18)**
- Change the definition of the ‘Do nothing’ rule as you have decided.	**Changing the definition of a rule (19)**
- Start the game.	**Running a model (7)**

Farmers and Rabbits

Somewhere in Wales a farmer has a field where he is trying to grow lettuces. Unfortunately, there is a rabbit in his filed which likes to eat the lettuces. What the farmer is trying to do is to catch the rabbit, so that he will 'save' his lettuces.

1. Load the game 'Farmers1'. **Loading a model (2)**

   Watch carefully what happens.

   a) Did the farmer manage to kill the rabbits?

   b) In the beginning there was only one farmer in the field. At the end of the game how many farmers are in the field?

   c) Do you know what the first farmer did so that he managed to get a helper?
   (If you want help, load again the game 'Farmers1' and pay your attention to what the farmer is doing.) **Loading a model (2)**

   d) Make a picture which describes what happened just before the new farmer appeared.

   before *after*

   | F | ? | → | F | F |

   e) Give a name to this action.

   f) Have a look at the list of rules for 'Farmers1'. Which rule of the list describes this action? **Opening the 'Rules' window of a filler (12)**

Loading a model (2)

2. Load the game ‘Farmers2’.

   a) Did the farmer manage to kill the rabbits this time?

   ____

   b) In the ‘Farmers1’ game, if there was an empty space next to the farmer, he could move there and plant a lettuce in the place he was before.
   Can you make a picture of this action?

before			*after*	
F		→	?	?

   c) In the ‘Farmers2’ game, if there was an empty space next to the farmer, he ___________________________

   ____

   ____

   d) Can you find out what the farmer was doing looking at the picture?

before			*after*	
F		→	F	L

3. Here are the pictures of the rules of the ‘Farmers2’ game.

	before			*after*	
Farmers	F		→		F
	F		→	F	L
Rabbits	R	L	→	R	
	R		→	R	R

   a) Can you write down looking at the pictures what the farmer can do?

   ____

   ____

   ____

   ____

   ____

   b) Can you write down looking at the pictures what the rabbit can do?

   ____

   ____

   ____

   ____

   ____

Answer the following questions:

c) If the game starts with one farmer, how many farmers do you think that will be at the end of the game; none, one or more than one?
Explain your answer.

____
____
____
____
____

d) If the game starts with two rabbits, how many rabbits do you think that will be at the end of the game; none, two or more than two?
Explain your answer.

____
____
____
____
____

Hunters, Foxes and Rabbits

In a field, rabbits and foxes are living. The rabbits are giving birth to new rabbits and the foxes are trying to catch the rabbits, so that they will be able to make new foxes. But when the hunters appear in the field, they are trying to trap the foxes and remove them.

1. Load the game 'Fox'. **Loading a model (2)**

   Watch carefully what happens.

   a) Did the fox manage to kill the rabbits?

   b) In the beginning there was only one fox in the field.
   At the end how many foxes are in the field?

   c) Do you know what the first fox did so that it managed to get a helper?
   (If you want help you can load again the game 'Fox' and pay your attention to what the fox is doing.) **Loading a model (2)**

   d) Make a picture which describes what happened just before the new fox appeared.

   before *after*

F	?	→	F	F

   e) Give a name to this action.

   f) Have a look at the list of rules for 'Fox'. Which rule of the list describes this action? **Opening the 'Rules' window of a filler (12)**

Loading a model (2)

2. Load the game 'Hunters1'.

   Watch carefully what happens.

   a) Write down what the rabbits, the foxes and the hunters are doing.

   Rabbits

   1st ____

   ____

   2nd ____

   ____

   etc. ____

   ____

   Foxes

   1st ____

   ____

   2nd ____

   ____

   etc. ____

   ____

   Hunters

   1st ____

   ____

   2nd ____

   ____

   etc.____

   ____

   b) Somebody else gave his/her answers by pictures:

	before		→	*after*	
Rabbits	R		→		R
Foxes	F		→	F	F
Hunters	H	F	→	H	H

   Is s/he right or wrong? Explain your answer.

   ____

   ____

   ____

   ____

   ____

   ____

3. Here are the pictures of the rules of a new game called ‘Hunters2’:

	before			*after*	
Foxes	F	R	→		F
	F		→		F
Rabbits	R		→		R
	R		→	R	R
Hunters	H		→	F	H
	H		→		H

a) Can you write down looking at the pictures what the rabbits can do?

b) Can you write down looking at the pictures what the foxes can do?

c) Can you write down looking at the pictures what the hunters can do?

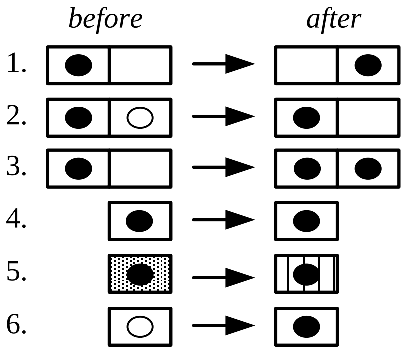
d) Answer the question:
If the game ‘Hunters2’ starts with two foxes, how many foxes do you think that will be at the end of the game; none, two, or more than two? Explain your answer.

If you want to check your answer, load the game ‘Hunters2’.

Loading a model (2)

Abstract

Here are some rules:



a) What does each rule do? What happens?

1. ______________________________
____

2. ______________________________
____

3. ______________________________
____

4. ______________________________
____

5. ______________________________
____

6. ______________________________
____

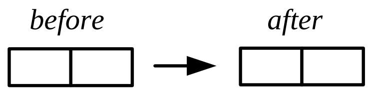
b) Can you make a story using at least two of these rules?

____
____
____
____
____
____

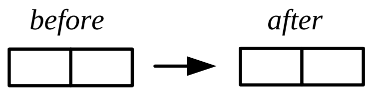
John's party

Yesterday John had a party and he had invited a few friends. When the party started, John walked around the room looking for Peter. When he met Peter, he told him the great news, that he got a new job.

a) Can you make a rule which describes John's walk around the room in order to find Peter?



b) Can you make a rule which describes what happened to Peter when he heard the news (from John)?



Could you these happening on the computer?

Somebody said that there are lots of rules that you cannot write in the computer. Here are some:

	before			*after*		
1.	F	S	→	F		‘Fishes eating sharks’
2.	P		→		P	‘People flying’
3.	N		→		N	‘News travelling all over the world’
4.	G	M	→	G		‘Germs eating meat’
5.		C	→	E		‘A car changing to an elephant’
6.		M	→			‘A man becoming invisible’

Do you agree with her/him or not? Explain your answer.

1. ______________________________

____

2. ______________________________

____

3. ______________________________

____

4. ______________________________

____

5. ______________________________

____

6. ______________________________

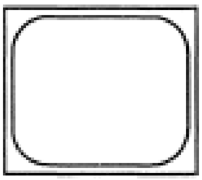
____

APPENDIX D

Instructions for Using WorldMaker in the Second Main Study

Instructions for using WorldMaker

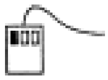
All the instructions have pictures next to them.



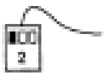
The first picture is like this. It shows where you should *look* on the screen.

The second picture looks like this. It shows what you should *do*.

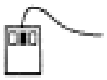
You may need to:



Click the SELECT button on the mouse.



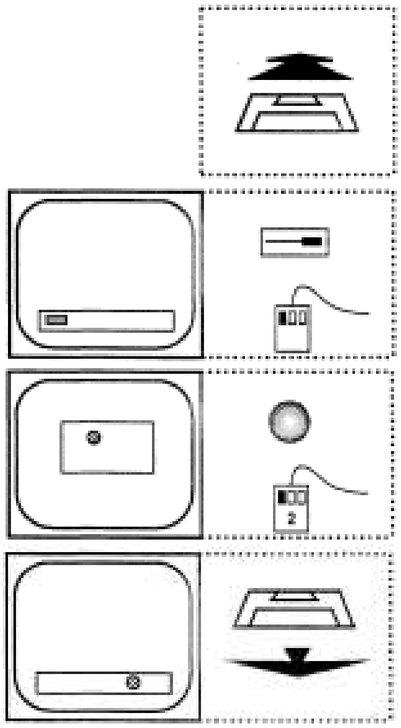
Double-click the SELECT button on the mouse.



Click the MENU button on the mouse.

Type something at the keyboard.

1 Starting up WorldMaker



Put the ‘WorldMaker’ disc in the computer.

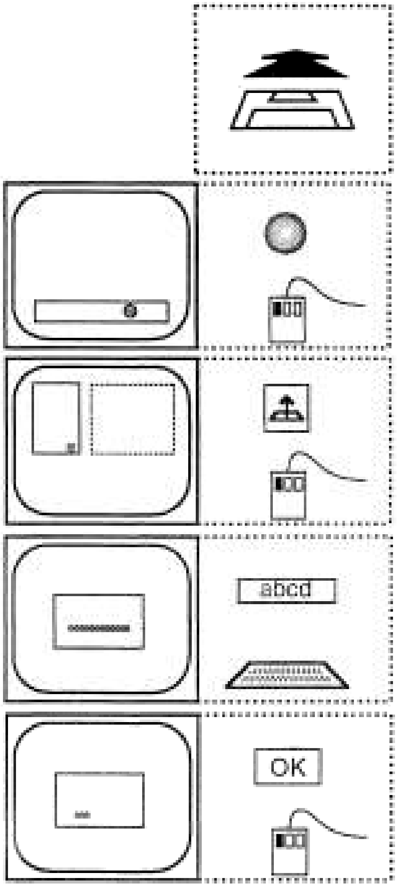
Click on the floppy disc icon on the icon bar on the bottom left. Use the SELECT (left) button on the mouse.

Double-click on the ‘!WorldMkr’ icon using the SELECT (left) button of the mouse.

Wait for a few seconds while it is loading. The icon should appear on the icon bar.

Remove the ‘WorldMaker’ disc from the computer.

2 Opening a worldkit



Put the ‘Worldkits’ disc in the computer.

Click on the ‘WorldMaker’ icon on the icon bar on the bottom right.

Two windows appear – the ‘Fillers’ window and the ‘Grid’ window.

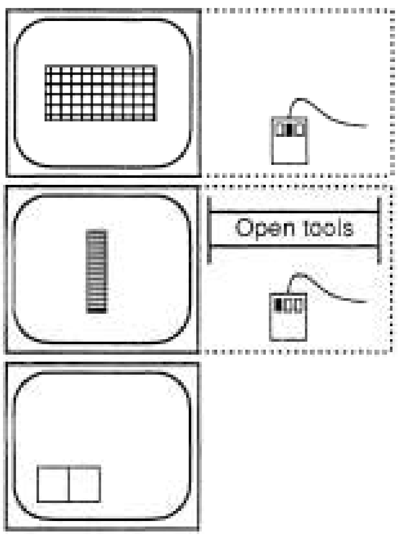
Click on the ‘open worldkit’ icon using the SELECT (left) button of the mouse.

A dialogue box opens.

Type the name of the worldkit.

Click on ‘OK’.

3 Opening the tools

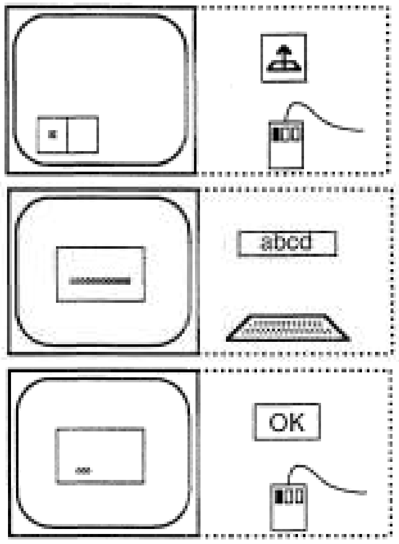


Open the ‘Grid’ menu, by clicking the MENU (middle) button over the ‘Grid’ window.

Click on the ‘Open tools’ option with the SELECT (left) button.

The ‘Tools’ window will open.

4 Opening a world



The 'Tools' window should be open ***(3)***.

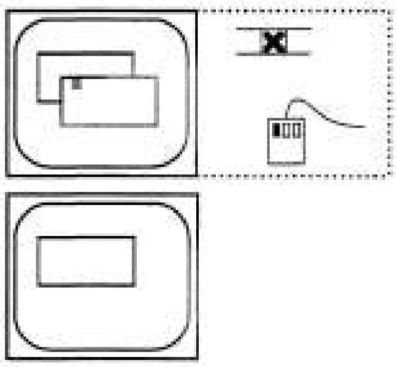
Click on the 'open world' icon.

A dialogue box opens.

Type the name of the world.

Click on 'OK'.

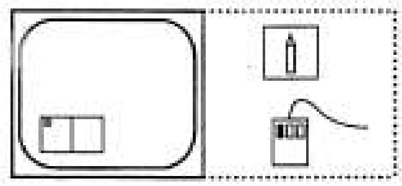
5 Closing a window



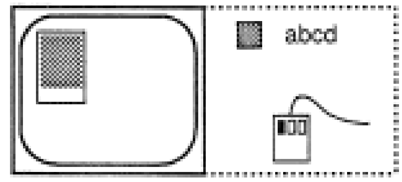
Click on the 'X' icon in the top left-hand corner of the window.

The window will close.

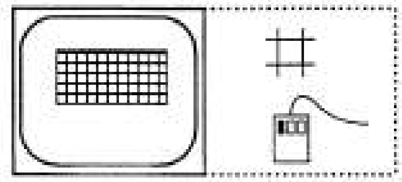
6 Plotting a filler on the grid (object or background)



Click on the 'pencil' icon in the 'Tools' window.

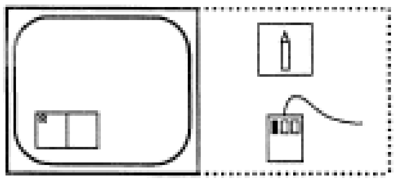


Click on a filler in the 'Fillers' window.

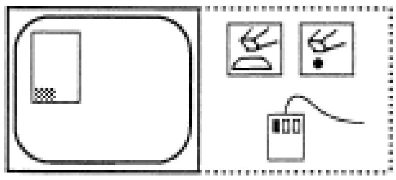


Click on a cell in the 'Grid' window.

7 Removing a filler from the grid (object or background)

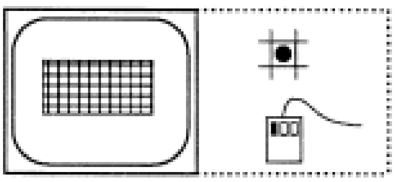


Click on the 'pencil' icon in the 'Tools' window.



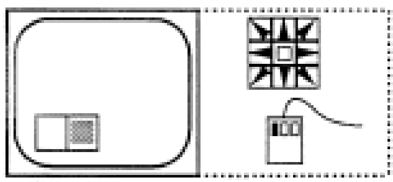
To remove backgrounds, click on the 'erase background' button in the 'Fillers' window.

To remove objects, click on the 'erase object' button.



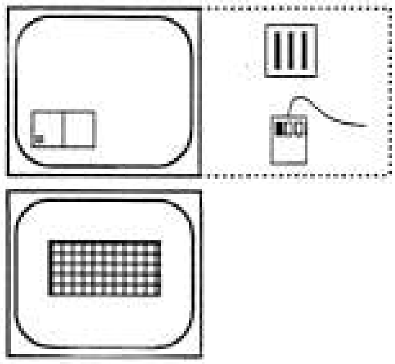
Click on the fillers you want to remove in the 'Grid' window.

8 Giving a direction to a filler



Before plotting a filler **(6)**, click on a direction in the 'Tools' window.

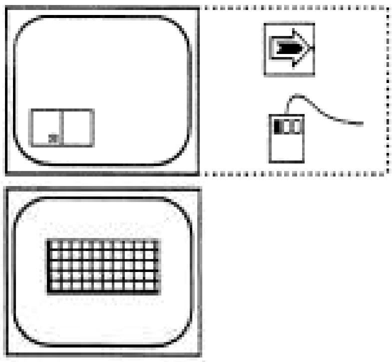
9 Stopping a world



Click on the ‘pause’ icon in the ‘Tools’ window.

When the world is not running, the lines on the grid change to red.

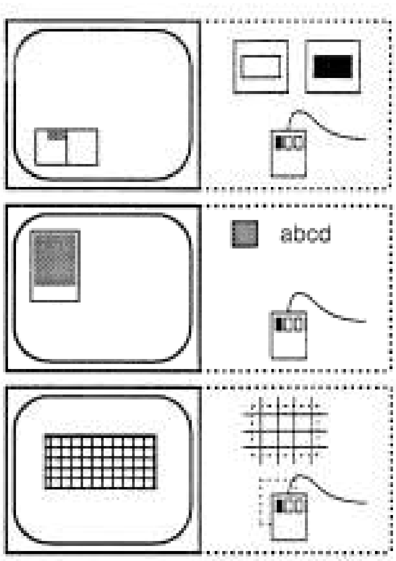
10 Running a world



Click on the ‘run’ icon in the ‘Tools’ window.

When the world is running, the lines on the grid change to black.

11 Plotting outlines or blocks of fillers

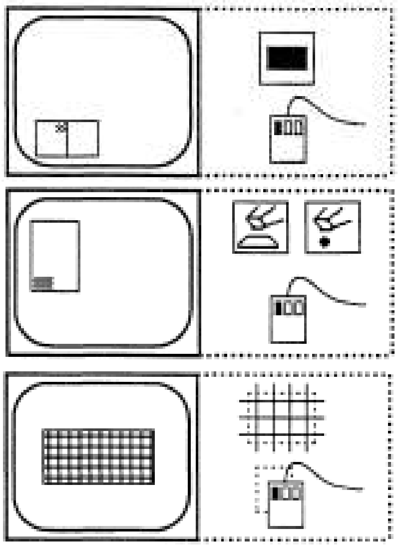


Click on the ‘outline’ or ‘block’ icon in the ‘Tools’ window.

Click on a filler in the ‘Fillers’ window.

Click on a cell in the ‘Grid’ window, but DO NOT RELEASE THE BUTTON. Drag the mouse to point to another cell. Release the button.

12 Removing a block of fillers



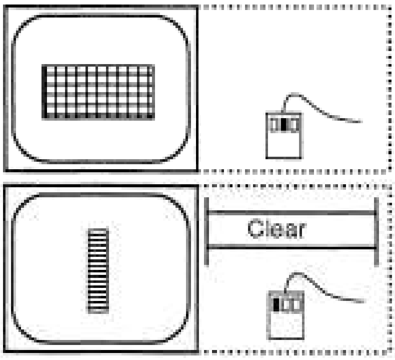
Click on the ‘block’ icon in the ‘Tools’ window.

To remove backgrounds, click on the ‘erase background’ button in the ‘Fillers’ window.

To remove objects, click on the ‘erase object’ button.

Click on a cell in the ‘Grid’ window, but DO NOT RELEASE THE BUTTON. Drag the mouse to point to another cell. Release the button.

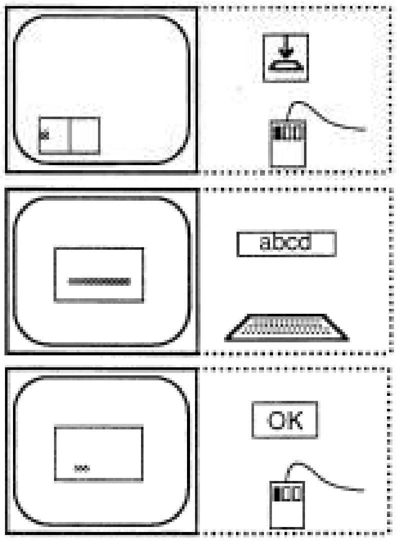
13 Clearing a world



Open the ‘Grid’ menu, by clicking the MENU (middle) button over the ‘Grid’ window.

Click on the ‘Clear’ option with the SELECT button.

14 Saving a world



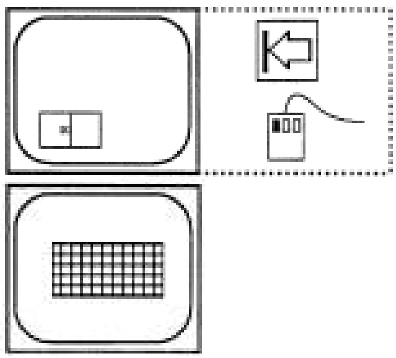
Click on the ‘save world’ icon in the ‘Tools’ window.

A dialogue box opens.

Type the name of the world.

Click on ‘OK’.

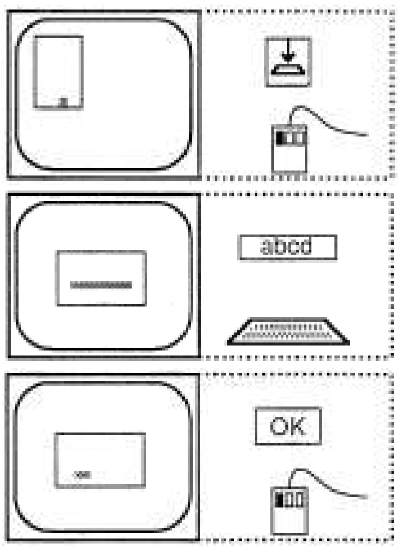
15 Restoring a world



Click on the ‘restore’ icon in the ‘Tools’ window.

This will restore the world to the state when it was last saved.

16 Saving a worldkit



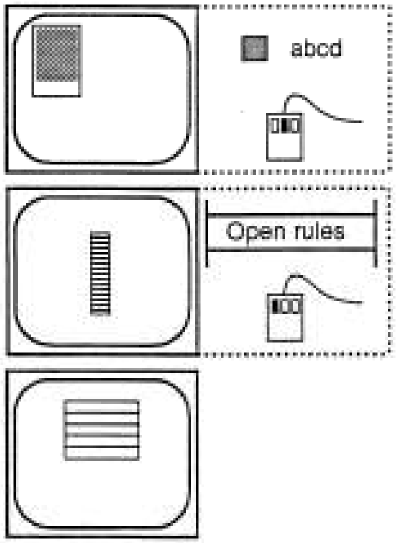
Click on the ‘save worldkit’ icon in the ‘Fillers’ window.

A dialogue box opens.

Type the name of the worldkit.

Click on ‘OK’.

17 Opening the 'Rules list' window of a filler



The 'Fillers' window should be open.

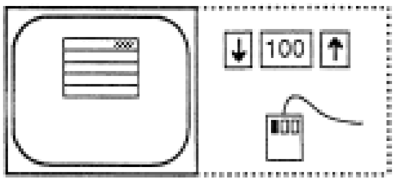
Open the 'Fillers' menu, by clicking the MENU button *over the filler that you want.*

Click on the 'Open rules' option with the SELECT button.

The 'Rules list' window will appear.

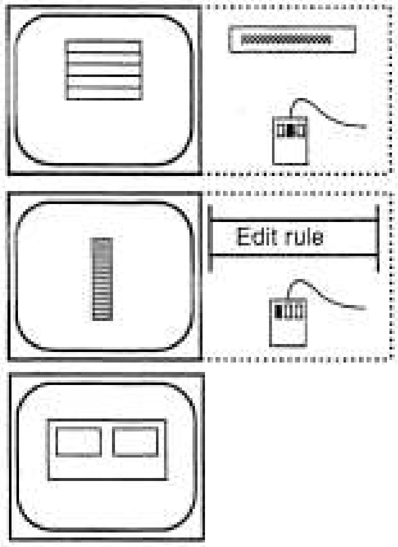
There are spaces for up to 5 rules. When a rule is not being used, 'Do nothing' is shown.

18 Changing the setting of a rule



After opening the 'Rules list' window **(17)**, you can change the setting to a new value. Click on the 'up' or 'down' arrows.

19 Opening the ‘Rule definition’ window



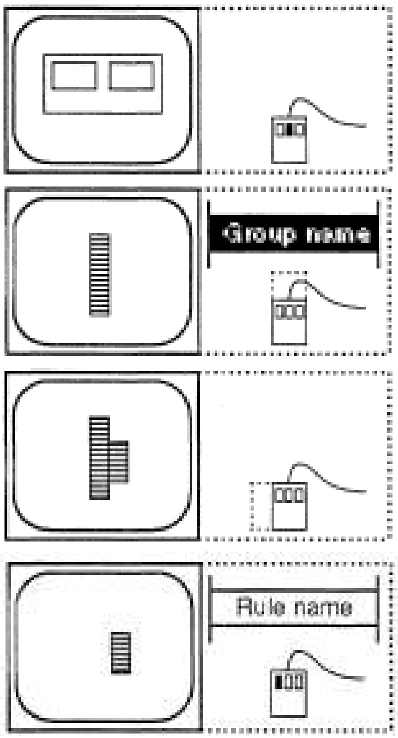
The ‘Rules list’ window should be open ***(17)***.

Click the MENU button *over the rule that you want.*

Click on the ‘Edit rule’ option with the SELECT button.

The ‘Rule definition’ window will open.

20 Changing the definition of a rule



The ‘Rule definition’ window should be open ***(19)***.

Open the menu, by clicking the MENU button over the ‘Rule definition’ window.

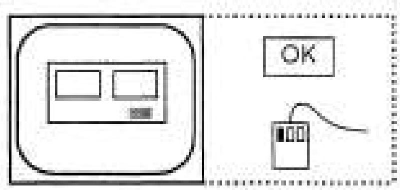
The menu shows the different groups of rules.

Move the mouse down, until the group you want is highlighted. DO NOT CLICK.

Move the mouse sideways to get a sub-menu.

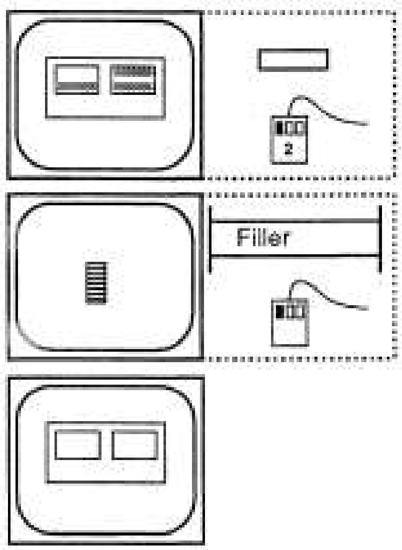
Click on the rule you want with the SELECT button.

For many rules you will also need to define other fillers **(21)**. These will appear as O1?, O2?, B1?,etc.



Click on ‘OK’.

21 Changing fillers in the rule definition

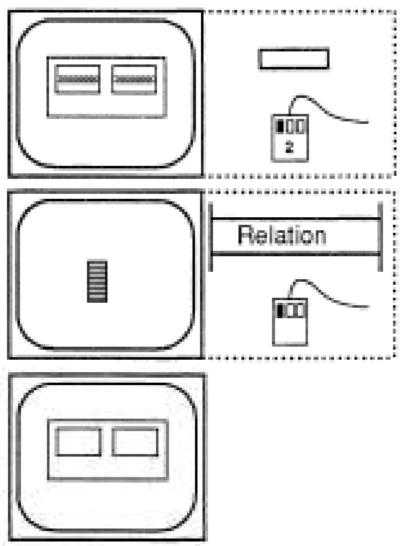


Double-click on the filler that you want to change.

Click on the filler you want with the SELECT button.

Close the window **(5)**, and the filler in the rule definition will be changed.

22 Changing relations in the rule definition

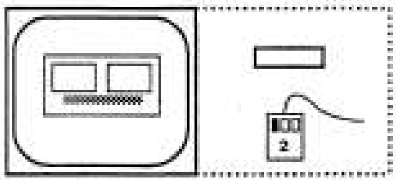


Double-click on the relation that you want to change.

Click on the relation you want with the SELECT button.

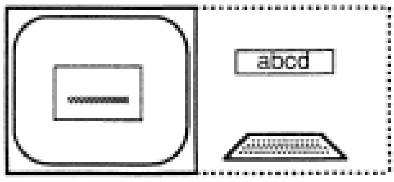
Close the window **(5)**, and the relation in the rule definition will be changed.

23 Changing the name of a rule



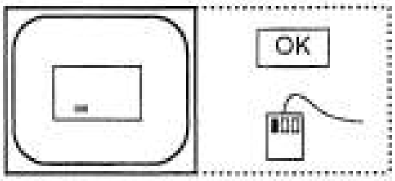
*The 'Rule definition' window should be open **(19)**.*

Double-click on the rule name.

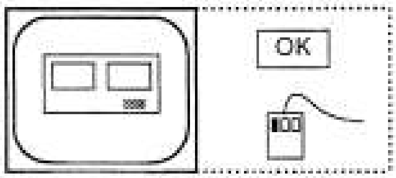


A dialogue box opens.

Type in the new name of the rule.



Click on 'OK' in the dialogue box.



Click on 'OK' in the 'Rule definition' window.

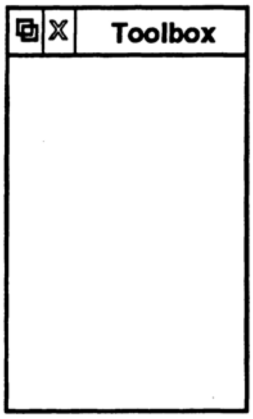
APPENDIX E

Second Main Study: Learning Tasks

Introduction to WorldMaker

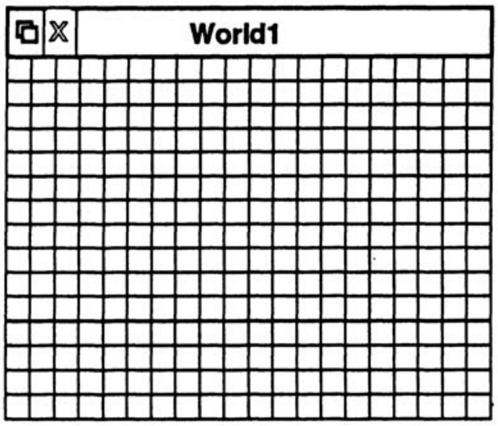
Using WorldMaker you can create your own *worlds*. These worlds may be like the *real* world, only *simpler*. They are not the *same* as the real world, and so we call them *models*. Because models are simpler, they can help us to understand what happens in the real world.

Think of part of the real world – for example, a street. It consists of *places*, like the road, pavements, shops and houses. It also consists of *things* that can move around these places – like cars, buses, bicycles and people. WorldMaker's models also consist of places and things.

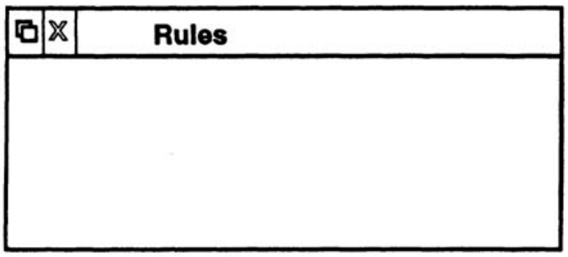


When you use WorldMaker, you will need a 'toolbox'. This contains the 'fillers' you need to create worlds, and the tools to do this.

There are two types of filler:
Backgrounds – these are like *places*.
Objects – these are like the *things* that move around the places.



This is where you build your world. It is called the 'Grid' window. You build your worlds by putting 'fillers' into the cells on the grid.



You will also see the 'Rules' window. This shows a list of rules which tells each of the fillers what to do.

The learning tasks

In the first three tasks you will learn how to create models by putting fillers on the grid.

These tasks are:

Bounce
Pond life
Glue

In the second set of three tasks you will learn about 'rule settings'. These control what the fillers do when they are on the grid.

These tasks are:

Checkout
Pests
Water

In the final set of three tasks you will learn how you can invent your own kinds of fillers. You can do this by writing your own rules.

These tasks are:

Cars
Rabbits
Coastline

To help you use the computer, there is a separate set of instructions. On the right hand side of each task, there are references in **bold type.** These tell you where to look in the instructions.

Sometimes you will see a picture of 'paper and pencil' like this. This means that you can do some writing on the worksheet.

Before starting any of the tasks, you will need to start up WorldMaker.

Starting up WorldMaker (1)

The worlds are stored in **'worldkits'**. Each task has a worldkit which contains the worlds that are needed for the task.

Bounce

Task 1/1

In this task, you will be looking at a world which uses ‘bouncy’ balls. You can make these balls move around the screen.

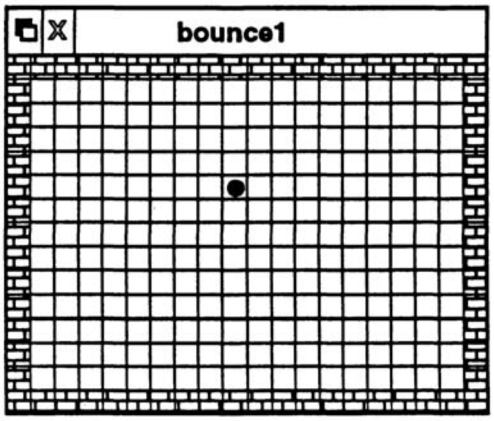
When they hit the wall, they bounce off it. When the balls hit each other, they disappear.

1. Open the ‘bounce’ worldkit, and then open the world ‘bouncel’.

Opening a worldkit (2)
Opening a world (4)

This world contains two types of ‘bouncy’ ball called ‘yellow’ and ‘blue’. Put a ‘yellow’ in one of the cells on the grid. Put a ‘blue’ on the grid. Try putting some more of each on the grid.

Plotting a filler on the grid (6)



Now get rid of these balls.

Removing a filler from the grid (7)

2. To make balls move around on the grid, you need to give them a *direction* first. Choose a direction, then put a ball in a cell on the grid. Try different balls in different directions.

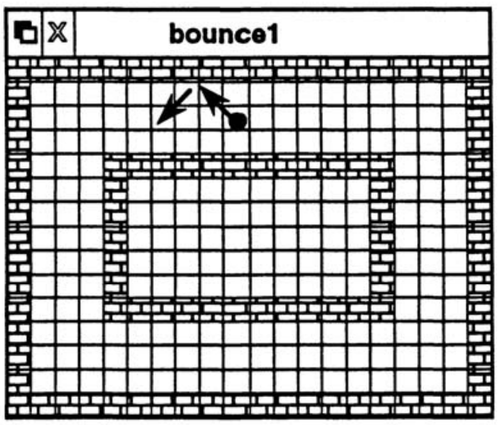
Giving a direction to a filler (8)

Now get rid of these balls. It can be difficult to do this when they are moving. It makes it easier if you *stop* the world to do this. After you have finished, set the world back to *run*.

Stopping a world (9)
Running a world (10)

3. Put some ‘walls’ on the grid to make a box that looks like this. You *could* use the ‘pencil’, but it is quicker to use the ‘outline’ tool. Can you make a ball bounce all the way around the inside?

Plotting outlines or blocks of fillers (11)



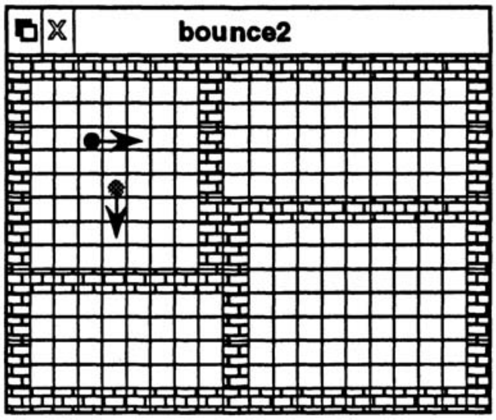
4. The next part of the task looks at different patterns in the way that balls bounce.

Close the world ‘bounce1’ and open the world ‘bounce2’.

Closing a window (5)
Opening a world (4)

There are four ‘boxes’ that you can put the balls in. In the first box, put a yellow ball that bounces up and down, and a blue ball that bounces from side to side. Do they hit each other and disappear?

Giving a direction to a filler (8)
Plotting a filler on the grid (6)



Try the other boxes, with the balls bouncing in the same way. In two boxes the balls will always hit each other and disappear. In the other two you can make the balls avoid each other. Can you find out which is which?

For the boxes where the balls do not hit, count the numbers of cells across. Count the number of cells down. Can you see a pattern? Do this for the other two boxes.

5. Try to make some boxes of your own.

First close the world ‘bounce2’, and then open the world ‘bouncel’ again.

Closing a window (5)
Opening a world (4)

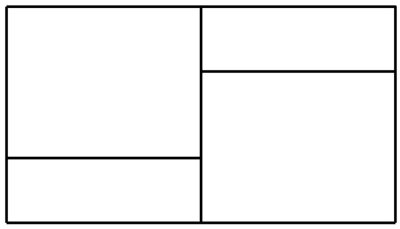
What is the *smallest* box you can make in which the balls *never* hit? What is the *smallest* box in which the balls *always* hit?

Task 1/1

Bounce

Name ____________________

A In this picture, put a tick in the boxes where the balls hit each other. Put a cross where they do not.



How many cells are there in the boxes where the balls do *not* hit?

	Across	Down
1st box		
2nd box		

How many cells are there in the boxes where the balls *do* hit?

	Across	Down
1st box		
2nd box		

Can you see any pattern?

____

____

B What is the *smallest* box you can make in which the balls *never* hit?

____

What is the *smallest* box you can make in which the balls *always* hit?

____

Pond life

Task 1/2

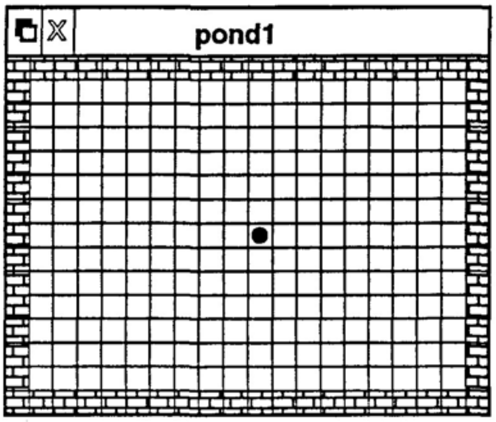
In this world, we shall be looking at a very small animal called ‘hydra’. You can see what a hydra looks like under a microscope. It has a thin body with lots of ‘arms’ or tentacles. It lives in ponds, and feeds on even tinier animals. These animals are found in the parts of the pond where there is a lot of *light*. So, if a hydra can find the *brightest* part of the pond, it will be able to find *food*.

1. Open the worldkit ‘pond’, and then open the world ‘pondl’.

Opening a worldkit (2)
Opening a world (4)

Put one of the objects ‘hydra’ onto the grid. Watch it carefully as it moves about. How could you describe the way it moves? Put some more on the grid. Do they all behave the same way?

Plotting a filler on the grid (6)



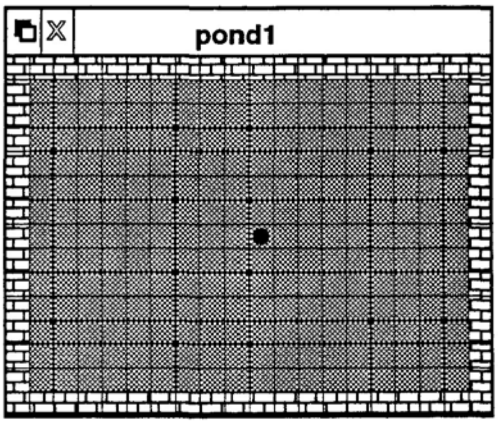
Now get rid of these hydras.

Removing a filler from the grid (7)

2. To start with, the grid is covered with the background called ‘bright’. Now we shall see what happens when hydra is on the background ‘dark’.

Put a block of ‘dark’ backgrounds on the grid. You *could* use the ‘pencil’, but it is much quicker to use the ‘block’ tool. Now put a hydra onto the 'dark' background.

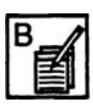
Plotting outlines or blocks of fillers (11)



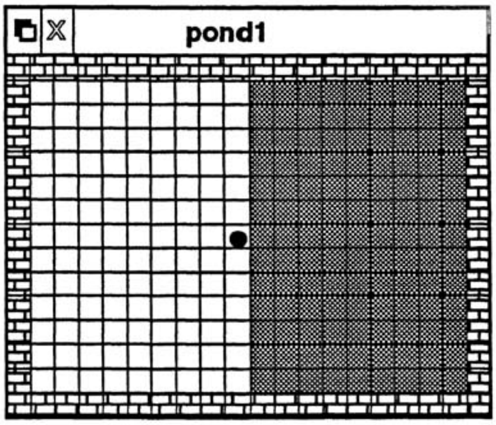
What does the hydra do? Put some more onto the ‘dark’ background. Do they all behave the same way?

Now get rid of these hydras. It can be difficult to do this while they are moving. It makes it easier if you *stop* the world to do this. After you have finished, set the world back to *run*.

Stopping a world (9)
Running a world (10)



3. Next we shall see whether the hydras ‘prefer’ to be on ‘bright’ or on ‘dark’ backgrounds.



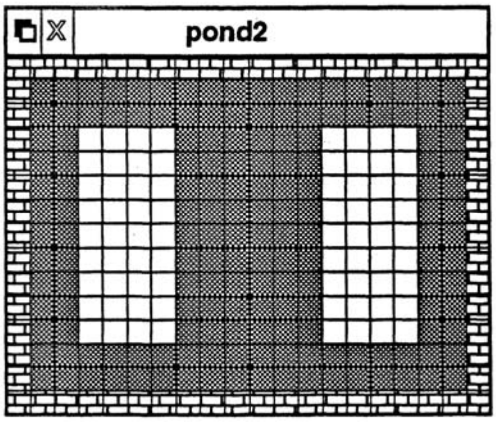
Fill one half of the grid with ‘dark’ and the other half with ‘bright’. Put a hydra near the middle of the grid. Watch the hydra carefully. How can you describe what it does?

Put some more on the grid. What happens to them?

4. Now we shall look at what hydras do when there is more than one ‘bright’ area.

Close the world ‘pondl’ and open the world ‘pond2’.

Closing a window (5)
Opening a world (4)



Put a hydra near the middle of the grid. What does it do?

Can you guess what would happen if you put more hydras on the grid? Try it. What happens?

Repeat what you have just done, but this time with the world ‘pond3’. This has a different pattern of ‘bright’ and ‘dark’. It has two ‘bright’ areas, but one is smaller than the other.

5. Try making your own patterns of ‘bright’ and ‘dark’.

Start with just one hydra, and watch it carefully. Guess what will happen with more. Then see if your guess was right.

Task 1/2

Pond life

Name ____________________

A Describe how the hydras move about.

____

____

B What do the hydras do on the 'dark' background?

____

____

C Which background does a single hydra spend more time on – 'bright' or 'dark'? Why?

____

____

What happens when you put on more hydras? Why do you think they do this?

____

____

D What happens when there is more than one 'bright' area?

____

____

Glue

Task 1/3

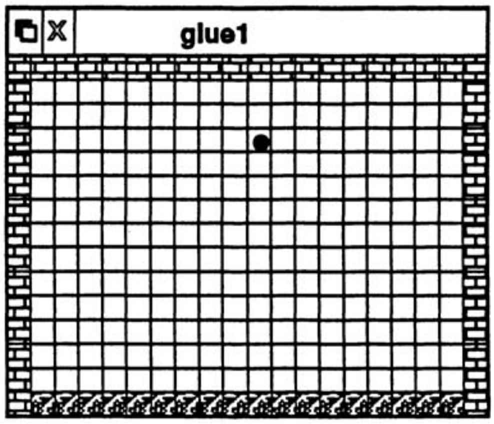
In this world, some of the fillers behave a bit like glue. You can see what shapes the glue makes when it ‘sets’ to a solid.

1. Open the ‘glue’ worldkit, and then open the world ‘gluel’.

Opening a worldkit (2)
Opening a world (4)

Put one of the objects ‘blue tube’ near the top of the grid. Watch carefully what happens.

Plotting a filler on the grid (6)



2. After you have seen what happens, try using ‘green tube’. First go back to the world you started with, by ‘restoring’ it.

Restoring a world (15)

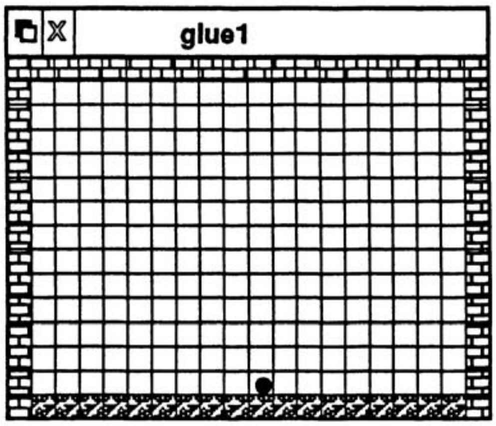
Then put on ‘green tube’ near the top of the grid, and watch carefully what happens.

Can you see any differences between ‘blue glue’ and ‘green glue’? Which is the ‘runniest’ glue?

3. Try the same thing again, but this time with the ‘tubes’ at the bottom of the grid. Do ‘blue tube’ first, and then ‘green tube’.

What can you see happening?

This may remind you a bit of a volcano. Why do you think that some volcanoes are quite flat, while others have steep sides? What kind of volcano would be made from ‘runny’ lava?



4. Try to see what shapes you can make by putting *two* tubes on the grid.

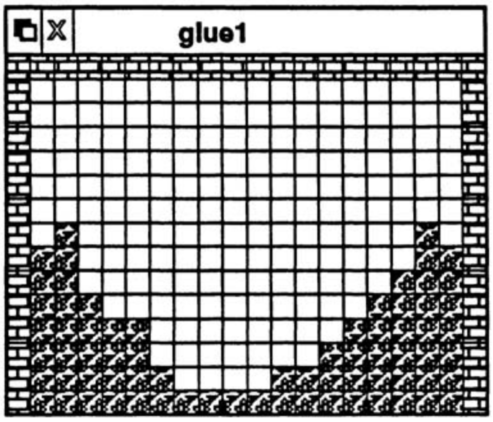
You could try two tubes of the same colour, or two of different colour. Try putting them in different positions on the grid.

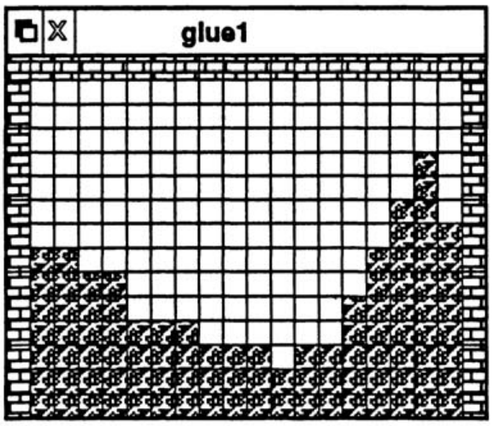
Try to predict what shapes you will make.

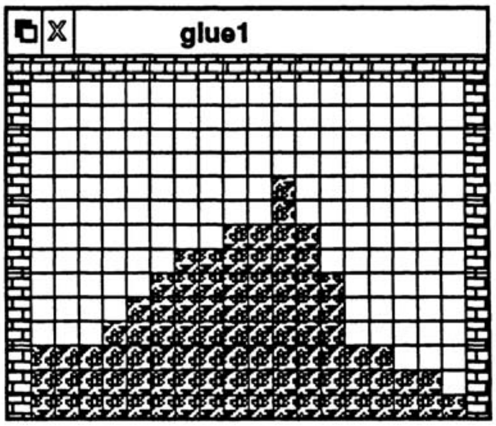
5. Here are three pictures of shapes that were made just by putting ‘tubes’ on the grid.

Can you work out how to produce shapes like these? How many tubes would you need? Which kinds of tube? Where would you put them?

Try out your ideas.







Task 1/3

Glue

Name ____________________

A What happens when you put a ‘tube’ on the grid?

What difference can you see between the ‘blue glue’ and the ‘green glue’?

B What happens when you put a ‘tube’ at the bottom of the grid?

Why do you think that some volcanoes are quite flat, while others have steep sides?

C Which tubes would you need to make shapes like these? Where would you put them? Draw them on these pictures.

- o blue glue
- ● green glue

Checkout

Task 2/1

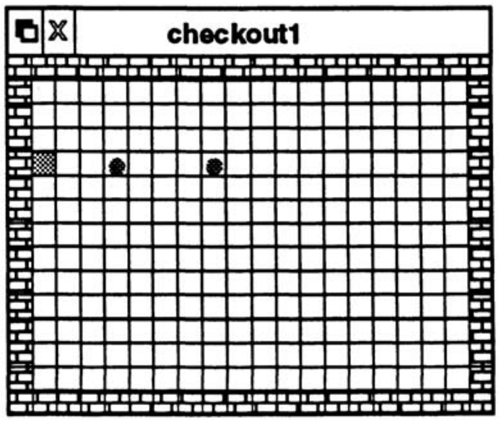
This task is about the checkouts in a supermarket. Shoppers come into the supermarket, and leave at the checkout. You can control how often they come and leave.

1. Open the ‘checkout’ worldkit, and then open the world ‘checkout1’.

Opening a worldkit (2)
Opening a world (4)

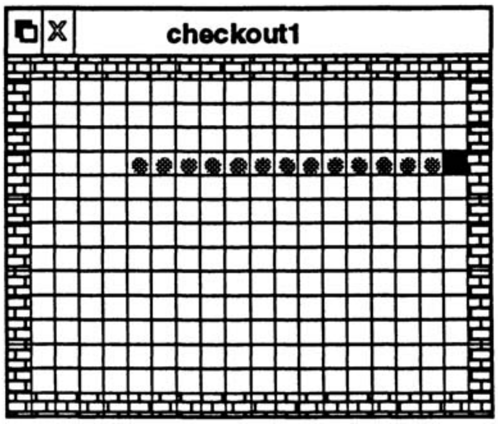
Put an ‘entrance’ (blue background) on the grid as shown. Watch how the shoppers appear and move across the grid. After a while, there will be a queue of shoppers.

Plotting a filler on the grid (6)



2. Now get rid of the ‘entrance’ so that no more shoppers can come in. Put a ‘checkout’ (red background) at the other end of the line of shoppers. Watch how the shoppers disappear. After a while all the shoppers have gone.

Removing a filler from the grid (7)



3. Put the entrance back where it was. Shoppers will now appear at the entrance, and disappear at the checkout.

Watch the shoppers at the checkout. Does it take the same time to serve each shopper? Or do some get served quicker than others?

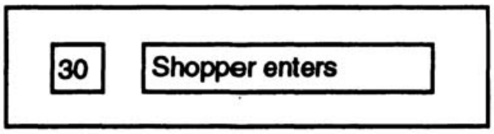
Watch the shoppers entering. Are they evenly spread out? Or are there gaps when not many shoppers come?

Watch the queue. Is it always the same length? Are there times when there is no queue?

4. You can also change how often shoppers arrive. To do this, look at the window showing the list of rules for ‘entrance’. In fact, ‘entrance’ has just one rule – ‘Shopper enters’.

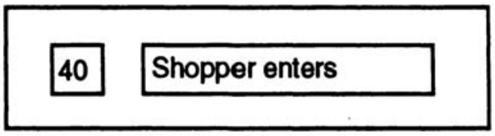
Next to the rule is a ‘slider’. It controls how often shoppers enter. Moving it to the right means that shoppers arrive more often. Moving it to the left means they arrive less often. If you make it ‘0’, then the rule stops working. This means that nobody enters.

Opening the ‘Rules list’ window of a filler (17)



At present the rule is set at ‘30’. Increase it to about ‘40’. Watch the queue again. What happens?

Changing the setting of a rule (18)



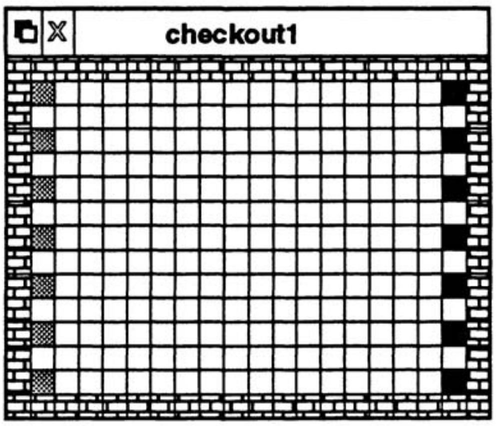
5. The ‘checkout’ also has one rule – ‘Shopper leaves’. Try increasing the setting of this rule. Watch what happens to the queue.

6. Imagine that you are the supermarket manager. You want to make sure that people do not wait too long at the checkout.

Set ‘Shopper enters’ to about ‘20’. How quickly must people be served to avoid getting a long queue? What is the *lowest* value for ‘Shopper leaves’ that you can use? Can you explain what happens if this rule is set higher? Or lower?

Try the same thing with the ‘Shopper enters’ rule set to a different value.

7. If you have time, you could compare different queues by setting up several entrances and checkouts on the same grid.



Task 2/1

Checkout

Name ____________________

A	Are the shoppers evenly spread out? ____________________ Does it take the same time to serve each shopper? ____________________ Is the queue always the same length? ____________________
B	What happens when you increase the setting of the rule 'Shopper enters'? ____________________ ____________________
C	What happens when you increase the setting of the rule 'Shopper leaves'? ____________________ ____________________
D	What is the lowest value for the 'Shopper leaves' rule, to avoid a long queue? ('Shopper enters' is set at '2'.) ____________________ What happens if it is set higher? Or lower? ____________________ ____________________

Pests

Task 2/2

Farmers need to plant crops to make them grow. Pests are enemies of farmers – they eat the crops that are planted. This world shows the struggle between farmers and pests.

1. Open the worldkit 'pests', and then open the world 'pestsl'.

Opening a worldkit (2)
Opening a world (4)

At the start, the grid is filled with bare 'earth' surrounded by a wall. Put a farmer onto the grid. Watch carefully what happens.

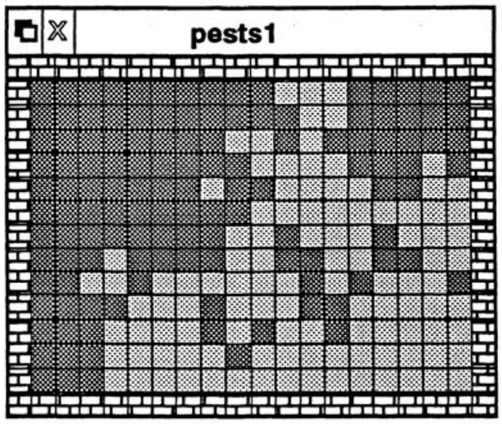
Plotting a filler on the grid (6)

Now put a 'pest' on the grid. Watch carefully what happens.

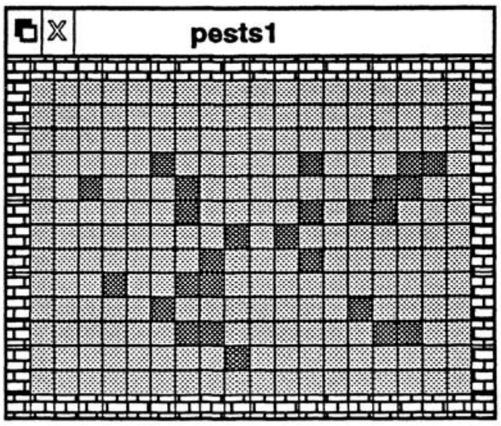
Remove the farmer and see what happens. (Stop the world if it is difficult to do this.)

Removing a filler from the grid (7)
Stopping a world (9)
Running a world (10)

2. Here is a picture of a grid in which there are about the same amounts of 'crops' and 'earth'. How many farmers and how many pests would you put on to get something like this? Try out your idea.

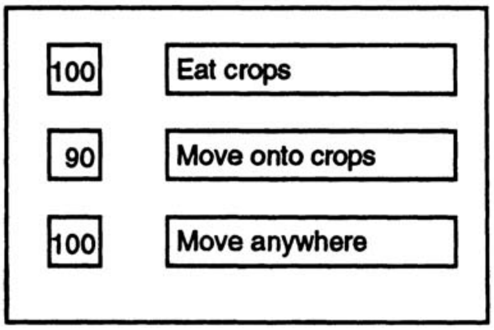


3. This picture shows a grid which is nearly all 'earth'. How many farmers and how many pests would you put on to get something like this? Try out your idea.



4. You can also change what the pests do. To do this, look at the window showing the list of rules for ‘pest’. A pest has three rules which tell it what to do. The first thing it tries to do is to ‘eat crops’. If it is not on ‘crops’ then it tries to ‘move onto crops’. If it cannot find any crops to move onto, then it will ‘move anywhere’.

Opening the ‘Rules list’ window of a filler (17)



Look at the rule ‘Eat crops’. Next to the rule is a slider. It controls how often pests eat crops.

At present the ‘Eat crops’ slider has been set on its *highest* value (100). Move it to the left to its *lowest* value (0). This means that pests *never* eat crops.

Changing the setting of a rule (18)

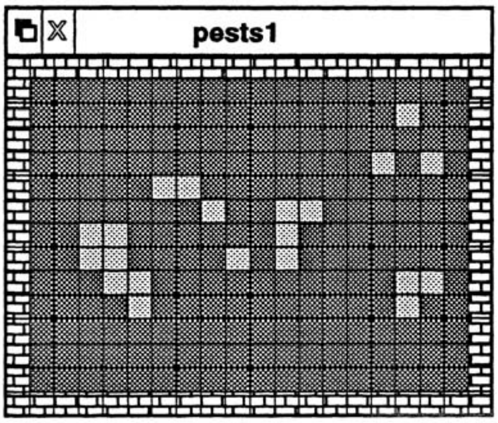
What happens on the grid? Can you explain this?

5. Change the setting of the ‘Eat crops’ rule to another value. Try and guess what will happen on the grid. Were you right?

Try changing the settings of the other rules for ‘pest’. Again, try to guess what will happen on the grid.

6. This picture shows a grid which is nearly all ‘crops’. How could you get the grid to look like this with the *same* numbers of farmers and pests? Try out your idea.

Is there more than one way of doing this?



Task 2/2

Pests

Name ____________________

A	What do the 'farmers' and the 'pests' do? ______________________________ ______________________________
B	How many 'farmers' and 'pests' did you use (to get about the same amount of 'crops' and 'earth')? ______________________________
C	How many 'farmers' and 'pests' did you use (to get nearly all 'earth')? ______________________________
D	What happens when you change the setting of the 'Eat crops' rule? ______________________________ ______________________________ What happens when you change the settings of the other rules for 'pest'? ______________________________ ______________________________
E	What rule setting did you use to get nearly all 'crops'? ______________________________ ______________________________

Water

Task 2/3

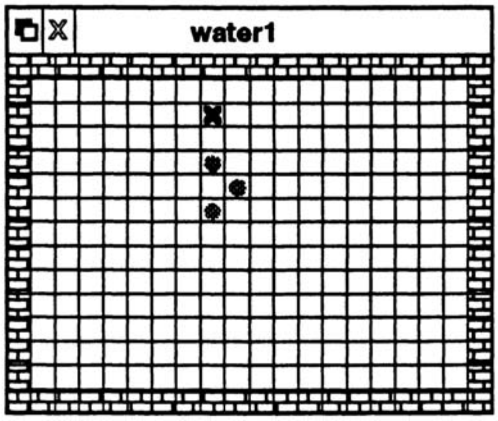
In this task, you will be looking at a world showing what happens when water runs over a rock. You can control how quickly the water flows, and how easily the water soaks into the rock.

1. Open the ‘water’ worldkit, and then open the world ‘waterl’.

Opening a worldkit (2)
Opening a world (4)

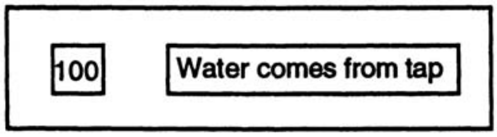
Put a ‘tap’ near to the top of the grid. Watch how the ‘water’ flows out of the tap.

Plotting a filler on the grid (6)



2. You can also change how quickly the water comes out of the tap. To do this, look at the list of rules for ‘tap’. There is just one rule for ‘tap’ – ‘Water comes from tap’.

Opening the ‘Rules list’ window of a filler (17)



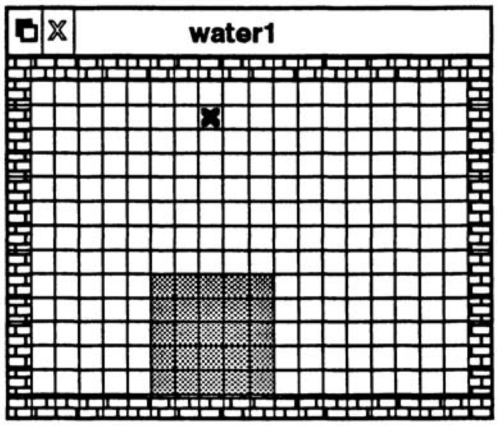
Next to this rule, there is a slider which controls how quickly water comes from the tap. At present, the value is set as high as it can go (100).

Move the slider to the left, to change the setting to about ‘20’. ‘Restore’ the world to the way it was at the start, and put the tap back on. What does it do now?

Changing the setting of a rule (18)
Restoring a world (15)

How can you turn the ‘tap’ off? Try it.

3. Clear the water from the grid again. Now fill some of the cells under the tap with ‘rock’. Turn the tap back on (increase the value of the rule setting). Watch what happens to the rock.

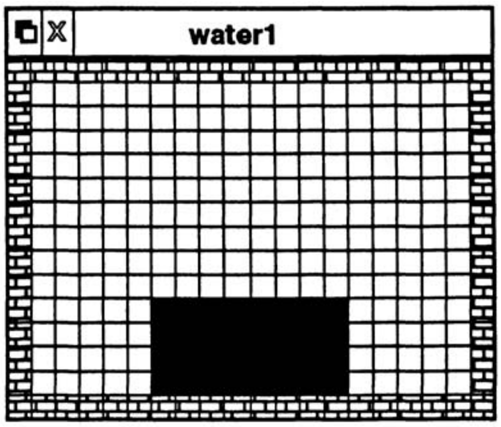


4. Look at the list of rules for ‘rock’. There are two rules. Switch off the second rule ‘Water passes through rock’ (change the value to ‘0’). Repeat what you did in part 3. What difference can you see? How do you explain this?

Switch off the first rule of ‘rock’ (‘Rock surface gets wet’). Repeat what you did in part 3. What difference can you see? How do you explain this?

5. Clear all the objects from the grid, by ‘restoring’ the world. Change the settings for the two rules in ‘rock’ back to ‘20’. Fill some cells with ‘wet rock’. Watch what happens.

The ‘wet rock’ has one rule – ‘Water drains from surface’. Switch this rule off, and repeat what you have just done. Do you notice any difference? Can you explain it?



6. How could you create the following?

a) a container being filled with water from a tap

b) a container being filled with water from a tap, but which leaks very slowly

c) a block of ‘rock’ which ‘soaks up’ some of the water it is in

Task 2/3

Water

Name ____________________

A What happens when you lower the setting of ‘Water comes from tap’?

____

____

How can you turn the tap off?

____

B What happens when you turn off the rule ‘Water passes through rock’?

____

What happens when you turn off the rule ‘Rock surface gets wet’?

____

C What does ‘wet rock’ do? How does the setting of the rule change this?

____

____

D What rule settings could you use for each of the following?

(a) a container being filled with water from a tap
(b) a container being filled with water from a tap, but which leaks very slowly
(c) a block of rock which ‘soaks up’ some of the water it is in

		(a)	(b)	(c)
rock	Rock surface gets wet			
	Water passes through rock			
wet rock	Water drains from surface			

Cars

Task 3/1

In this task, you will be looking at a world with cars which move about on roads. You will be creating your own *rules* to make the cars move around.

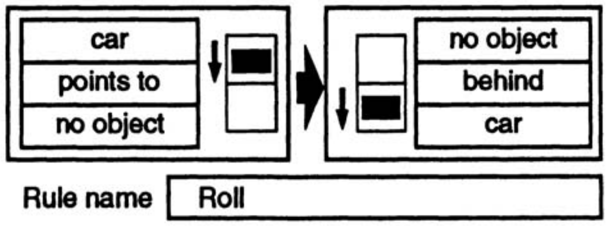
1. Open the 'cars' worldkit, and then open the world 'carsl'.

Opening a worldkit (2)
Opening a world (4)

Put a 'car' on the grid. It does not do anything. Put on another 'car' giving it a *direction*. It still does not move. The reason is that it does not have any rules telling it to move. Look at the 'Rules list' window for 'car'. You will see that all its rules are 'Do nothing'.

Giving a direction to a filler (8)

2. To make the car move, you need to give it a rule. This picture shows a rule that will make the car move. It shows what happens if a 'car' is pointing to a cell with 'no object' in it. It moves into the cell, and leaves an empty cell behind it.

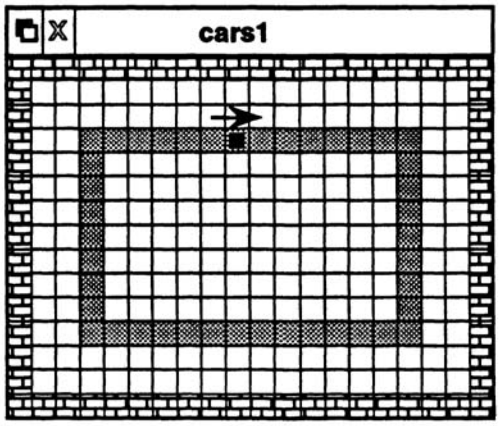


Open the 'Rule definition' window of **Rule 4** in the list for 'car'. Change the definition so that it shows the rule above.

Opening the 'Rule definition' window (19)
Changing the definition of a rule (20)

The car already on the grid should move and stop at the wall. Try putting more cars on with different directions.

3. Get rid of the cars on the grid. Make a 'road' and put a car with a direction on it as shown.

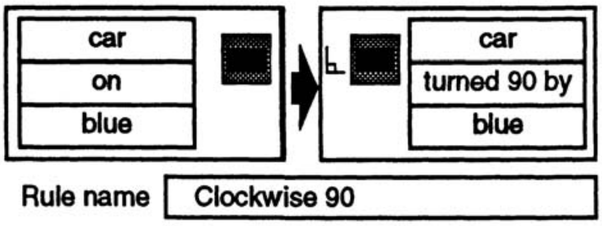


At the moment the car does not stay on the road. What you need to do is to make it *turn at the corners*. To do this you could put a 'blue' background at each corner. Then you could give the car a rule which makes it turn right when it is on a 'blue' background.

The next section tells you how to do this.

4. Open the ‘Rule definition’ window of **Rule 1** in the list for ‘car’.

Define the rule shown in this picture. It shows that if a car is on a blue background, it turns 90 degrees clockwise (i.e. to the right).

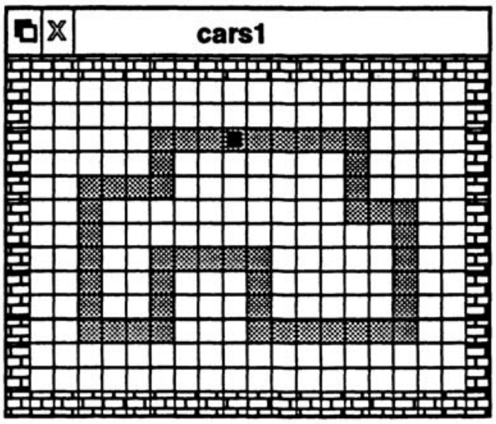


Put ‘blue’ backgrounds at each corner of the ‘road’. Try the car again. It should now go round the road.

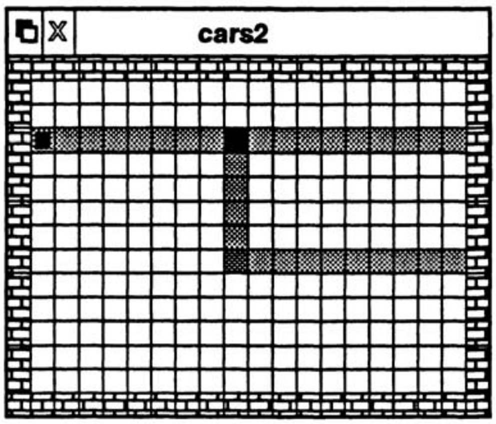
5. Try making your own ‘road’ with any shape you like. Here is an example. The car now needs to turn *left* as well as right.

You can make it do this by putting different backgrounds at the corners – ‘blue’ to make it turn right and ‘red’ to make it turn left.

You will need to give the car another rule – to tell it to turn left on ‘red’ backgrounds. Define **Rule 2** like you did for a blue background – but this time make it ‘*Anticlockwise 90*’ for a *red* background.

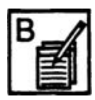


6. Cars do not always need to follow the same road. Open the world ‘cars2’.

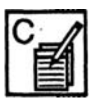


By changing the sliders, you can control how often the rule works. Which rule could you change, so that cars sometimes go down the *straight* road and sometimes the other? Try it.

Changing the setting of a rule (18)



7. In the world ‘cars3’, there are *three* different roads. Try to make rules so that cars may go down *each* of the three roads.

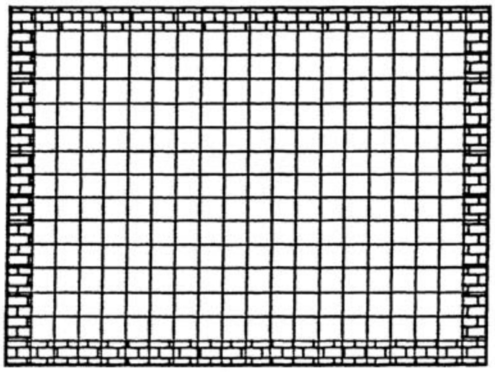


Task 3/1

Cars **Name ____________________**

A Draw the shape of the road you made on this grid. Use different colours or different types of shading to show 'road', 'blue' and 'red'. Fill in the key.

☐ road
☐ blue
☐ red



B What rules did you use to make the car go down the other path?

____

____

Which rule setting could you change so that cars sometimes go down one road, and sometimes the other?

____

C What rules could you make so that cars may go down each of the three roads? What settings could you use?

____

____

____

____

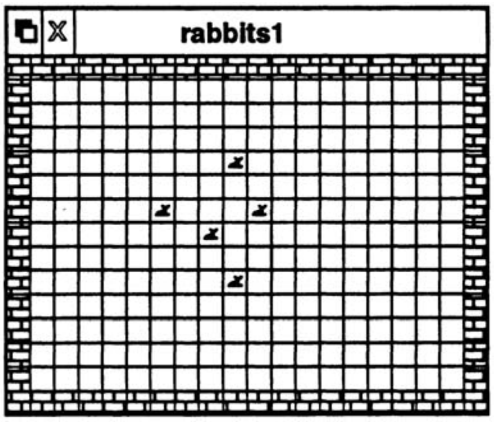
Rabbits

Task 3/2

Rabbits breed and make more rabbits. Rabbits also die. If they did not, the world would quickly fill up with rabbits. Rabbits are also killed by other animals such as foxes. This model looks at populations of rabbits and foxes *(prey and their predators).* You will be creating your own *rules* for rabbits and for foxes. You will tell them what you want them to do.

1. Open the ‘rabbits’ worldkit, and then open the world ‘rabbitsl’.

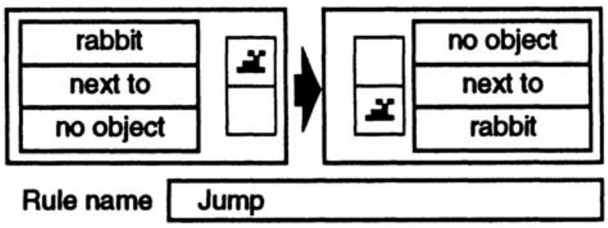
Opening a worldkit (2)
Opening a world (4)



Put a few ‘rabbits’ on the grid. As you can see, they do not do anything. They do not even move around.

The reason that they do nothing is that they do not have any rules telling them what to do. Look at the ‘Rules list’ window for ‘rabbit’. You will see that all its rules are ‘Do nothing’.

2. To make a rabbit move, you need to give it a rule. This picture shows a rule that will make a rabbit move. It shows what happens if a rabbit is next to a cell with no object in it. It moves or ‘jumps’ into the empty cell.



Open the ‘Rule definition’ window of **Rule 4** in the list for ‘rabbit’. Change the definition so that it shows the rule above.

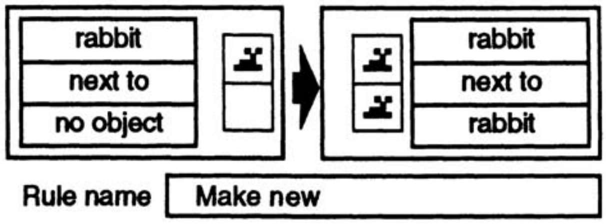
Opening the ‘Rule definition’ window (19)
Changing the definition of a rule (20)

3. The rabbits on the grid should now start to move around.

Try making them move around less often – use the slider to change the value of the rule setting.

Changing the setting of a rule (18)

4. Now we shall try to get the rabbits to ‘breed’ or make new rabbits. Here is a rule which does this.



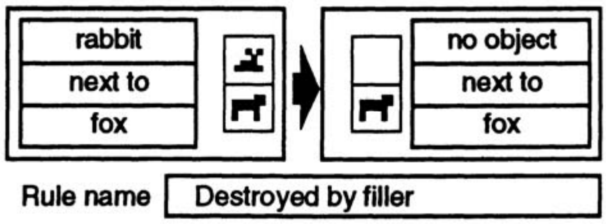
Changing the definition of a rule (20)

Open the ‘Rule definition’ window of **Rule 1** in the list for ‘rabbit’. Change the definition so that it shows the rule above.

If you want, you can choose your own name for this new rule (e.g. ‘Breed rabbits’).

Watch what happens to the rabbits. In *our* world, they fill up the whole grid.

5. Why is it that rabbits have not filled up the *real* world? One reason is that they are killed by *predators*, e.g. foxes. Here is a rule in which rabbits are eaten by foxes.



Open the ‘Rule definition’ window of **Rule 2** in the list for ‘rabbit’. Change the definition so that it shows the rule above.

Put some foxes on the grid, and see what happens. Try to guess what will happen if you alter each of the rule settings. Try this. Were you right?

6. Try adding some of your own rules. Here are some suggestions, but you could make up some of your own. Some rules make sense, while others may seem a bit strange.

Can you get a *stable* population of rabbits – one that does not fill up the whole grid or does not die out? Try altering the rule settings to do this.

fox next to no object → no object next to fox
rabbit by itself → no object by itself
rabbit next to rabbit → no object next to rabbit
fox next to rabbit → fox next to fox

fox by itself → no object by itself
rabbit by itself → fox by itself
fox next to no object → fox next to fox

Task 3/2

Rabbits

Name ____________________

A What happened to the rabbits when you gave them the 'Make new' rule? Describe what you saw on the grid.

____

____

B What happened when you altered each of the following rule settings?

rabbit next to no object → no object next to rabbit

____

rabbit next to no object → rabbit next to rabbit

____

rabbit next to fox → no object next to fox

____

C What other rules did you make?

____

____

____

What happened on the grid?

____

____

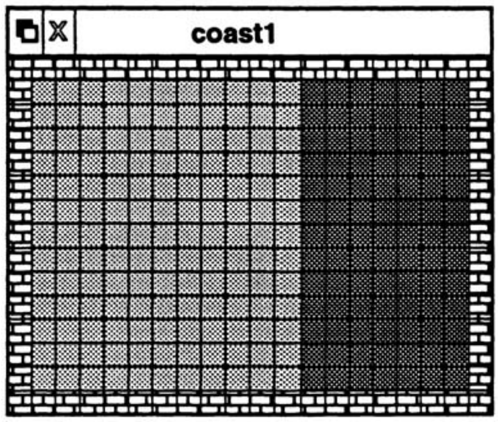
Coastline

Task 3/3

Looking at a map of this country, you can see the shape of the coastline. This shape does not change *very much*, but it *does* change *slowly*. The coastline in some parts of the country changes faster than in others. There are places where houses have disappeared, as the sea has washed the land away. In this task, you will be looking at a world in which the shape of the coastline is changed by the sea. You will be creating your own *rules* for the land and the sea. You will tell them what you want them to do.

1. Open the ‘coast’ worldkit, and then open the world ‘coast1’.

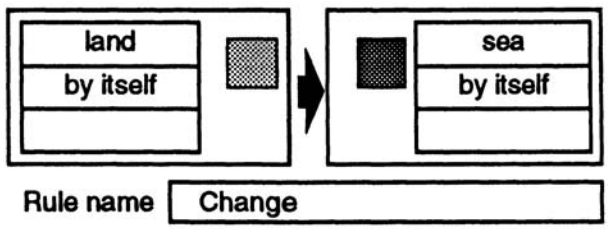
Opening a worldkit (2)
Opening a world (4)



The grid shows a simple ‘map’. On the left, each cell has an object called ‘land’. On the right, each cell has an object called ‘sea’. At the moment, nothing happens. The land is not washed away by the sea.

The reason that ‘land’ does nothing is that it does not have any rules telling it what to do. Look at the ‘Rules list’ window for ‘land’. You will see that all its rules are ‘Do nothing’.

2. To make the land do something, you need to give it a rule. This picture shows a rule in which land changes to sea. It is the simplest rule which changes land into sea.



Open the ‘Rule definition’ window of **Rule 1** in the list for ‘land’. Change the definition so that it shows the rule above.

Opening the ‘Rule definition’ window (19)
Changing definition of a rule (20)

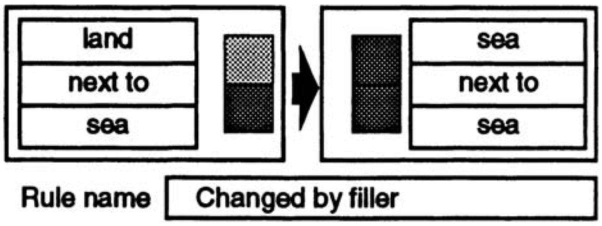
3. The land should now change into sea.

This happens very quickly. Try making it happen more slowly. Change the value of the rule setting to ‘10’. Restore the world and watch it happen again.

Changing the setting of a rule (18)
Restoring a world (15)

Do you think that this looks like land being washed away by sea?

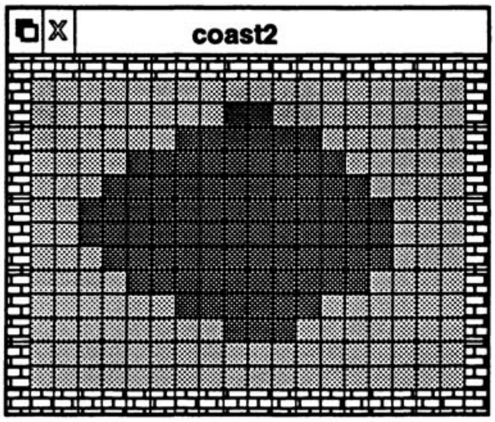
4. In the last 'world', land changed into sea, but it did not look like it was being washed away. It would be better if only the land *next to the sea* was changed into sea. Here is a rule which does this.



Open the 'Rule definition' window of this rule again. Change the definition so that it shows the rule above.

Restore the world and watch what happens. How can you explain this?

5. Try seeing what happens with this rule with different patterns of sea and land. Open the world 'coast2'. This shows an 'island' of land with sea around it. Can you guess what will happen? Try it. Were you right?



Do the same thing with the world 'coast3'. This shows a 'harbour' of sea. Guess what will happen. Were you right?

6. So far we have looked at land being washed away by sea. But you can also get land being *formed* by the sea. The sea can carry land away from one place and leave it at another. What rules could you use to *create* land from the sea? You could also try having rules which both washed away the sea and created it.

Here are some suggestions of some rules you could try. Some rules make sense, while others may seem a bit strange. You could also make up some of your own. Try out your rules on the each of the worlds 'coast1', 'coast2' and 'coast3'.

land next to sea → land next to land

land next to sea → sea next to land

sea next to land → sea next to sea

sea next to sea → land next to land

land next to land → sea next to land

sea by itself → land by itself

sea next to land → land next to sea

Task 3/3

Coastline

Name ____________________

A	What happened on the grid with the rule 'land next to sea → sea next to sea'? How can you explain this? ______________________________________ ______________________________________
B	What happened when you use the following worlds? an island (coastline2) ______________________________________ a harbour (coastline3) ______________________________________
C	What other rules did you make? ______________________________________ ______________________________________ ______________________________________ What happened on the grid? ______________________________________ ______________________________________

APPENDIX F

Second Main Study: Research Tasks

Cats

Name:

This is a story about cats.

Try imagining that there are some creatures who are born as cats but when they meet dogs, they become dogs. Later on they change to mice.

Here is a cats 'world'.

From the 'cats' worldkit open the tools. **Opening the tools (3)**

Then open the world 'cats1'. **Opening a world (4)**

This 'world' contains three different kinds of creatures, called 'cats', 'dogs' and 'mice'.
Does anything happen if the grid has only 'cats' on it?

Put a few 'dogs' on the grid. Watch what happens. **Plotting a filler on the grid (6)**

1. Is what happens in the story like what happens in the computer world? How? (*Cats.1*)

___

___

___

2. Are they different in any way? (*Cats.2*)

___

___

___

3. Does this story make sense? (*Cats.3*)

4. Does this 'world' make sense? (*Cats.4*)

5. Can you write your own story that makes sense? For example, the cats could be caterpillars. What might the dogs and mice be? (*Cats.5*)

Diseases

Name:

This is a story about diseases.

On the 1st of December everybody was fine in the classroom. On the 5th one child didn't feel very well, he had got an influenza, but he didn't go home, he stayed at school and at the end of the week ten children were sick. A few weeks later, the same kind of influenza was spread over again, but this time the children didn't get sick, they were immune.

Here is a diseases 'world'.

From the 'disease' worldkit open the tools. Then open the world 'disease1'.

Opening the tools (3)
Opening a world (4)

This 'world' contains three types of persons, called 'healthy', 'ill' and 'better'.
Does anything happen, if the grid has only 'healthy' on it?

Put a few 'ill' on the grid.
What happens now?

Plotting a filler on the grid (6)

1. How does the disease spread in the story? (*Diseases.1*)

____

____

____

2. How does the disease spread in the computer world? (*Diseases.2*)

3. Is what happens in the computer world like the story? How? (*Diseases.3*)

4. Is what happens with real diseases like what happens in the computer world? (*Diseases.4*)

5. Can you think of something which happens in real diseases but doesn't happen in the computer world? (*Diseases.5*)

Here is another story about diseases.

In the morning, Mary had a headache and high temperature. She went to work as a babysitter looking after a three years old child. Two days later, she realised that she had got flu. She was worried about the baby, but when she called the family, they told her that the baby was fine.

1. Is what happens in this story like what happens in the computer world? How? (*Diseases.6*)

    ____

    ____

    ____

2. In what ways is it different? (*Diseases.7*)

    ____

    ____

    ____

3. Is what happens in the story about Mary like what happens in the story about the sick school child? How? (*Diseases.8*)

    ____

    ____

    ____

News

Name:

Here is a news 'world'.

From the 'news' worldkit open the tools.
Then open the world 'news1'.

Opening the tools (3)
Opening a world (4)

This 'world' contains three types of persons, called 'unaware', 'informed' and 'bored'. Does anything happen if the grid has only 'unaware' on it?

Put a few 'informed' on the grid.
Watch what happens.

Plotting a filler on the grid (6)

1. How does the news spread in the computer world? In the end, have all unaware persons changed to informed? (*News.1*)

____

____

____

Here are two stories about news.

Story 1: John's party

Yesterday John had a party and he had invited a few friends. One of them was Peter. When John met Peter he told him the great news, that he had got a new job. Even though he told him that it was secret, Peter started to talk about it. After an hour, most people knew about it and no one talked about it any more.

1. How did the secret spread in the party? In the end, did everybody know about it? (*News.2*)

2. Does this story make sense? Why? (*News.3*)

3. Is what happens in John's party the same as what happens in the computer world? (*News.4*)

Story 2: Nuclear accident

In the morning people didn't know anything about a serious nuclear accident which had happened. But after listening to the news at 6 p.m. most people knew about it.

1. How did the news about the nuclear accident spread? In the end, did everybody know about it? (*News.5*)

2. Does this story make sense? Why? (*News.6*)

3. Is what happens in the nuclear accident story like what happens in the computer world? (*News.7*)

4. In what ways is it different? (*News.8*)

5. Is what happens in John's party like what happens in the nuclear accident? How? (*News.9*)

6. In what ways is it different? (*News.10*)

Disease/Rumour

Name:

These are the rules of a ‘diseases’ story:

before		*after*
H I	→	I I
I	→	B

H: healthy person
I: ill person
B: better person

These are the rules of a ‘rumour’ story:

before		*after*
IG IN	→	IN IN
IN	→	B

IG: ignorant person
IN: informed person
B: bored person

1. Is the ill person like the informed person in any way? (*Disease/Rumour.1*)

2. Is what happens in the story about diseases the same as what happens in the story about rumour? How? (*Disease/Rumour.2*)

3. In what ways is it different? (*Disease/Rumour.3*)

Cat/Disease

Name:

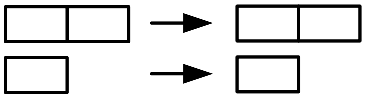
Here is a story about cats:

Try imagining that there are some creatures who are born as cats but when they meet dogs, they become dogs. Later on they change to mice.

C: cat
D: dog
M: mouse

Can you write some rules which show what is happening in the story to the cats and to the dogs? (*Cat/Disease.1*)
Put the letters C, D and M in the correct boxes.

before *after*



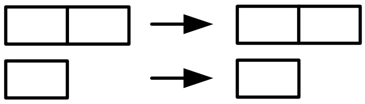
Here is a story about diseases:

Healthy people can only catch a cold when they meet other people who already have a cold. Eventually people with colds get better.

H: healthy person
I: ill person
B: better person

Can you write some rules which show what is happening in the story to the healthy and to the ill persons? (*Cat/Disease.2*)
Put the letters H, I and B in the correct boxes.

before *after*



1. Is the cat like the healthy person in any way? (*Cat/Disease.3*)

____

____

____

2. Are your ‘cats’ rules similar to your ‘diseases’ rules? In what ways? (*Cat/Disease.4*)

____

____

____

3. In what ways are they different? (*Cat/Disease.5*)

____

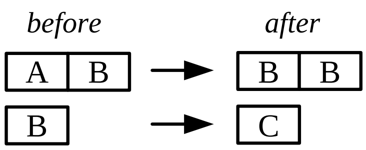
____

____

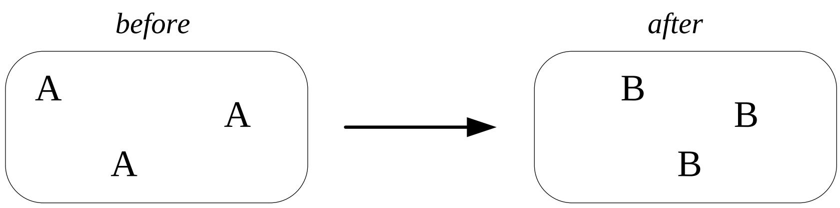
ABC

Name:

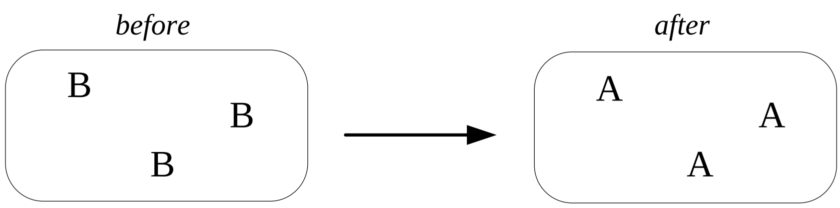
Here are the rules in a ‘world’ about A, B and C:



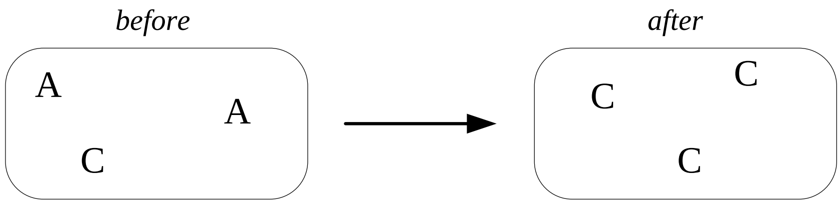
Could you see this happen in this computer world? Explain your answer.



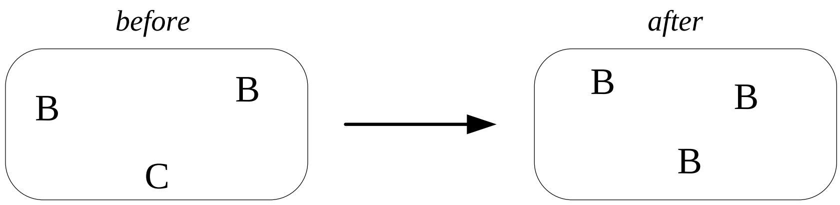
(*ABC.1*)



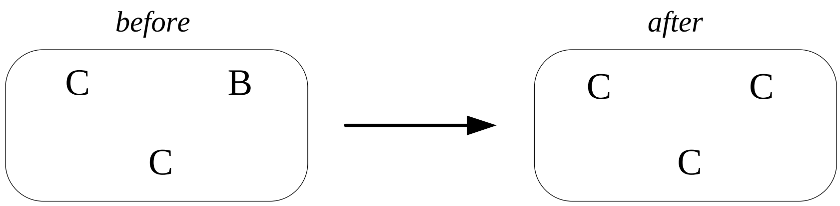
(*ABC.2*)



(*ABC.3*)

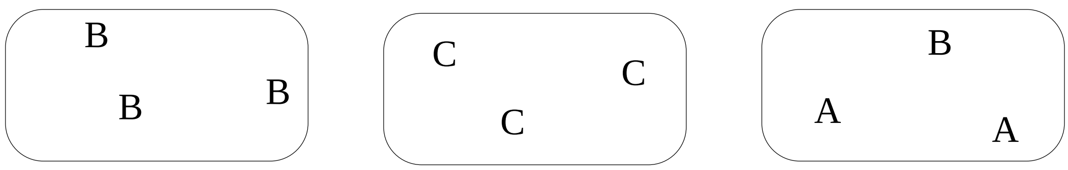


(*ABC.4*)



(*ABC.5*)

Can you put these pictures in order, according to the rules? Explain your answer. (*ABC.6*)



Name:

Natasha has made a diseases ‘world’, with a few rules. But when she runs it, no one in her ‘world’ gets ill.

What might be wrong? Tick the boxes below.

	strongly agree	partly agree	partly disagree	strongly disagree
1. All her rules must be wrong.	☐	☐	☐	☐
2. One of the rules must be wrong.	☐	☐	☐	☐
3. A rule is missing.	☐	☐	☐	☐

Natasha goes on trying to get people in her ‘world’ to become ill. She wonders whether adding more rules might get this to happen.

What should she do?

	strongly agree	partly agree	partly disagree	strongly disagree
1. She may need to add a rule.	☐	☐	☐	☐
2. She may need to change a rule.	☐	☐	☐	☐
3. She should work out why people were not getting ill, before doing anything.	☐	☐	☐	☐

> Peter makes a ‘world’ about rabbits. He wants the screen to fill up with rabbits starting from a few rabbits and foxes. He is pleased because this is what happens.
> Gill objects: “*Your ‘world’ is no good. It has a rule where rabbits eat foxes, and that doesn't make sense. It could not happen.*”
> Peter: “*That doesn’t matter. My ‘world’ is all right because it gives the result I want.*”

What do you think?

	strongly agree	partly agree	partly disagree	strongly disagree
1. Do you agree with Peter?	☐	☐	☐	☐
2. Do you agree with Gill?	☐	☐	☐	☐
3. A ‘world’ which does what you want is all you need.	☐	☐	☐	☐
4. It is more important to get rules which make sense than to get the ‘world’ to do what you want.	☐	☐	☐	☐

> Ann makes a crazy ‘world’ about boats and sharks. She expects the shark to ‘give birth’ to boats! She is worried because that doesn’t happen.
> Parvin says: “*Your ‘world’ doesn’t make sense. It can’t happen. That’s why it doesn’t work.*”
> Ann objects: “*No. My ‘world’ doesn’t work because I’ve got the rule wrong.*”

What do you think?

	strongly agree	partly agree	partly disagree	strongly disagree
1. Do you agree with Parvin?	☐	☐	☐	☐
2. Do you agree with Ann?	☐	☐	☐	☐
3. A ‘world’ which does what you want is all you need.	☐	☐	☐	☐
4. A ‘world’ which makes sense is all you need.	☐	☐	☐	☐
5. If you want to get the ‘world’ to do what you want, you should get the rules right, regardless of whether they make sense or not.	☐	☐	☐	☐

Mary and Abdul are making a ‘world’ which shows a forest fire spreading and burning down a whole forest. They think of some objects which might be useful. Which of the objects underneath which they thought of might be useful for making this ‘world’?

☐ a tree

☐ whole forest

☐ a tree on fire

☐ fire spreading

☐ a burnt tree

☐ burnt forest

How did you decide?

____

____

____

Draw one rule you might try out for a forest fire ‘world’.

before | | → *after* | |

Explain what this rule shows.

____

____

____

Can you think of any other objects or rules you would prefer? (Write on the back of this paper).

APPENDIX G

Sessions of the Second Main Study

SCHOOL A			
Session	**Learning Tasks**	**Research Tasks**	**Duration**
1	'Bounce'		70 min
2	'Pests'	'Cats'	70 min
3		'Diseases'	70 min
4	'Rabbits'	'News'	70 min
5		'Disease/Rumour', 'Cat/Disease', 'ABC', The modelling questionnaire	70 min

SCHOOL B / GROUP A				***SCHOOL B / GROUP B***			
Session	**Learning Tasks**	**Research Tasks**	**Duration**	**Session**	**Learning Tasks**	**Research Tasks**	**Duration**
1	'Pond life'		30 min	1	'Bounce'		30 min
2	'Pond life'		30 min	2	'Bounce'		30 min
3		'Cats', 'Diseases'	45 min	3		'Cats', 'Diseases'	45 min
4	'Pests'		30 min	4	'Pests'		30 min
5	'Rabbits'		30 min	5	'Cars'		30 min
6	'Rabbits'		30 min	6	'Cars'		30 min
7		'Disease/Rumour', 'Cat/Disease', 'ABC', The modelling questionnaire	45 min	7		'Disease/Rumour', 'Cat/Disease', 'ABC', The modelling questionnaire	45 min

SCHOOL C / GROUP A				***SCHOOL C / GROUP B***			
Session	**Learning Tasks**	**Research Tasks**	**Duration**	**Session**	**Learning Tasks**	**Research Tasks**	**Duration**
1	'Pond life'		45 min	1	'Pond life'		45 min
2		'Cats'	45 min	2		'Cats'	45 min
3	'Pests'	'Diseases'	45 min	3	'Pests'	'Diseases'	45 min
4		'News'	45 min	4		'News'	45 min
5	'Rabbits'		45 min	5	'Rabbits'		45 min
6		'Disease/Rumour'	45 min	6		'Disease/Rumour'	45 min
7		'Cat/Disease', 'ABC', The modelling questionnaire	45 min	7		'Cat/Disease', 'ABC', The modelling questionnaire	45 min